This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.
+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.
+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.
+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

B 1,298,422

DIRECT-CURRENT
MOTOR AND GENERATOR TROUBLES

McGraw-Hill Book Co. Inc.
PUBLISHERS OF BOOKS FOR
Coal Age ▿ Electric Railway Journal
Electrical World ▿ Engineering News-Record
American Machinist ▿ Ingeniería Internacional
Engineering & Mining Journal ▿ Power
Chemical & Metallurgical Engineering
Electrical Merchandising

DIRECT-CURRENT
[OTOR AND GENERATOR TROUBLES
OPERATION AND REPAIR

BY

THEODORE S. GANDY
DESIGNING ELECTRICAL ENGINEER OF DIRECT CURRENT
MACHINERY, GENERAL ELECTRIC COMPANY, SINCE 1904

AND

ELMER C. SCHACHT, Lt. J. G., U. S. N. R. F.
IN CHARGE OF ELECTRICAL INSTRUCTION AT THE UNITED STATES
NAVY SCHOOL OF TURBINE ENGINEERING, SCHENECTADY, N. Y.

First Edition

McGRAW-HILL BOOK COMPANY, Inc.
NEW YORK: 239 WEST 39TH STREET
LONDON: 6 & 8 BOUVERIE ST., E. C. 4
1920

ENGIN. LIBRARY
TK
2612
.G21

COPYRIGHT, 1920, BY THE
McGRAW-HILL BOOK COMPANY, INC.

THE MAPLE PRESS YORK PA

PREFACE

The chief purpose of this book is to give the methods, which many years of experience have proved to be both simple and effective, for tracing and remedying direct current motor and generator troubles. In addition, the questions of the selection, operation, care and repair of direct current machinery are analyzed from the standpoint of the operator.

The theories of why a motor or generator will run, as well as the problems and fundamentals underlying the design of direct current machinery, have been very completely given and expounded in numerous excellent books on the market. But it is our belief that there is a vast army of operators in the electrical world who are greatly interested in why the motor or generator will not run, and it is to supply information on this topic that the present work has been written. Throughout, it is assumed that the operator is confronted with the question of selection of the best machine for his purpose; then with the question of the best operation of that machine and in case of troubles, with their tracing and effective remedying.

In all cases, an effort has been made to treat the subjects in as general a way as possible so as to include all methods in good practice. Standard machines are described and illustrated so as to in no way limit and restrict the information to the operation of special types. We are greatly indebted to the General Electric Company, the Westinghouse Electric Manufacturing Company, and the Allis-Chalmers Company for their kindness in furnishing the illustrations for this publication.

THE AUTHORS.

SCHENECTADY, N. Y.,
April, 1920.

361150

INTRODUCTION

There are many books on matters electrical, some people believe, more than necessary or desirable. There are books on the theory of electrical engineering, on the theory of electrical apparatus, of electric systems and methods of operation. They are necessary, for on the theory of electrical engineering rests our giant electrical industry, which could not have developed without it. It was this thorough theoretical foundation which has enabled electrical engineering, though the last of the great engineering branches, to progress with the wonderful rapidity which outstripped all others. There are numerous books on apparatus and machinery design. While perhaps not one out of ten electrical engineers may become a designer, they are necessary and useful. There are numerous books on practical electrical engineering, good, bad and indifferent.

But for every designer or theorist, there are two or three electrical engineers who have to do with electric motors or generators, their operation, management and care, and therefore Messrs. Gandy & Schacht's book appears to me as extremely useful, filling a serious gap in our electrical literature. I may call it a biology, pathology and therapy of the electric machine.

It deals with the electric machine in all its conditions, in health and when in trouble. It gives the characteristics, describes the construction and the nature of the electric motor and generator, shows and illustrates the numerous troubles which may occur in motors and generators—almost as many as there are diseases of mankind—teaches how to diagnose the trouble, that is, to find out what is the matter, how to cure it, to remedy the trouble, and how to keep the machine in good shape, that is, in first class operating condition.

Attempts to write such a book have been made before, but it can be done successfully, so that the book is of real use to the engineer who has to do with electrical machinery, only by an engineer who has lived with motors and generators of all kinds for many years in a large manufacturing company, and so has been able to become fully familiar with every phase of the subject, and who by years of teaching experience has become able also to transmit his knowledge and experience to the reader. Now this has been the case with the authors of the following work, and therefore I consider it as a most valuable addition to the electrical literature, which will be of interest and value to every engineer.

CHARLES P. STEINMETZ.

March 25, 1920.

TABLE OF CONTENTS

DIRECT-CURRENT MOTOR AND GENERATOR TROUBLES

CHAPTER I

TYPES OF MOTORS AND THEIR USES

General Construction—Types of Motors—Standard Electrical Connections for Motors—Uses of Different Types of Motors—Information to be Supplied to the Manufacturer when Ordering

TYPES OF MOTORS AND THEIR USES

In ordering direct-current motors for new installations or in replacing or adding to old units, the question arises of selecting the motor best suited for the purposes at hand. Frequently defects in operation and more often great inefficiency can be traced to the poor judgment of the buyer when selecting the motor.

It is the purpose here to outline the general construction and characteristics of the different types of standard motors upon the market. The details of construction and the illustrations of the motor in the process of building, serve to acquaint the operator with views of each individual part while in assembly. The use to which the motor is to be put and the conditions under which it is to operate should be carefully considered before a selection is made.

DESCRIPTION OF DIRECT-CURRENT MOTORS

GENERAL CONSTRUCTION

Direct-current motors are composed of three distinct parts—a stationary electrical element, commonly called the field, a revolving element called the armature and the assembly parts. The field construction comprises the magnet frame, pole pieces, main and commutating, and the field windings, main and commutating. The armature is composed of a laminated core carrying the winding and the commutator. The assembly parts consist of the brush rigging, the pillow blocks and bearings and the base.

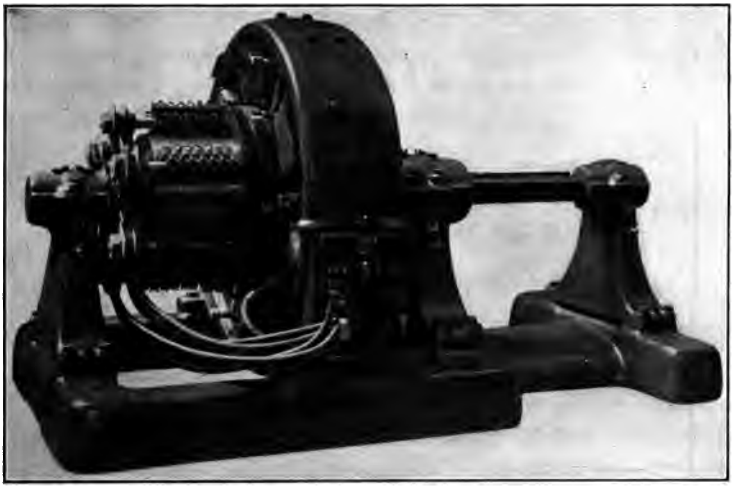


Fig. 1.—Shunt wound motor.

Six pole, commutating pole motor, shunt wound, with pulley supported between two bearings instead of being overhung. Note no sliding rails furnished and base drilled for foundation bolts; therefore an idler pulley for belt tightening is required. Note also all armature and field leads brought to a common terminal board; and brush rigging supported from the pillow block.

The magnet frame consists of a cast steel or cast iron frame as shown in Figure 2 made in one piece in small units and in larger units divided into halves horizontally and bolted together. Sometimes the entire inside circumference is turned out to receive the pole pieces and in other cases bosses or pads are cast on the casting and turned or machined to fit the poles. The frame is then drilled and tapped to accommodate the bolts holding the pole pieces. Feet are cast on the lower half of the frame and drilled to receive the holding down bolts.

The main pole pieces consist of a series of mild steel punchings or laminations pressed together in a press and held together by rivets. A very common construction is to have a square or round hole near the magnet frame end of each pole piece in which a steel bar is inserted. Then instead of drilling and tapping directly into the laminations to receive the frame bolts, the steel bar is drilled, tapped and fitted to the frame bolts. This feature produces a stronger and more reliable job since there is danger of the laminations spreading or of weak threading in case the laminations themselves are drilled and tapped to receive the bolts.

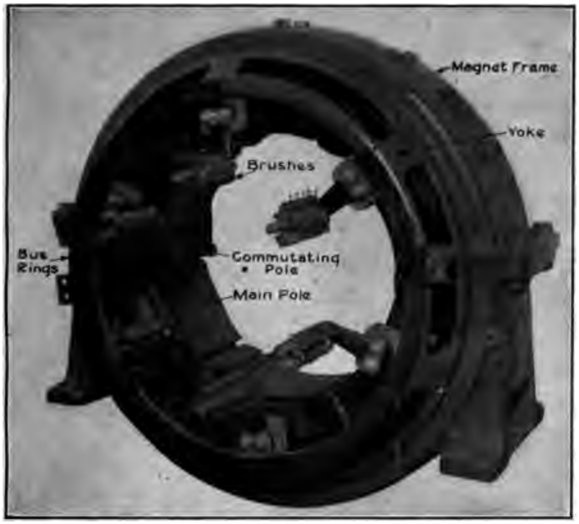


FIG. 2.—Assembled frame and brush rigging.

Showing field structure of six pole, commutating pole, slow speed, (260 R.P.M.) compound wound, 250 volt, 135 horse power motor. Note brush rigging supported from magnet frame; all field coils mounted on removable spools; and field frame split horizontally.

The commutating pole pieces are either composed of a series of laminations riveted together or of a solid core. In the case of the laminated structure, they are secured to the frame in the same two ways as described for the main pole pieces,

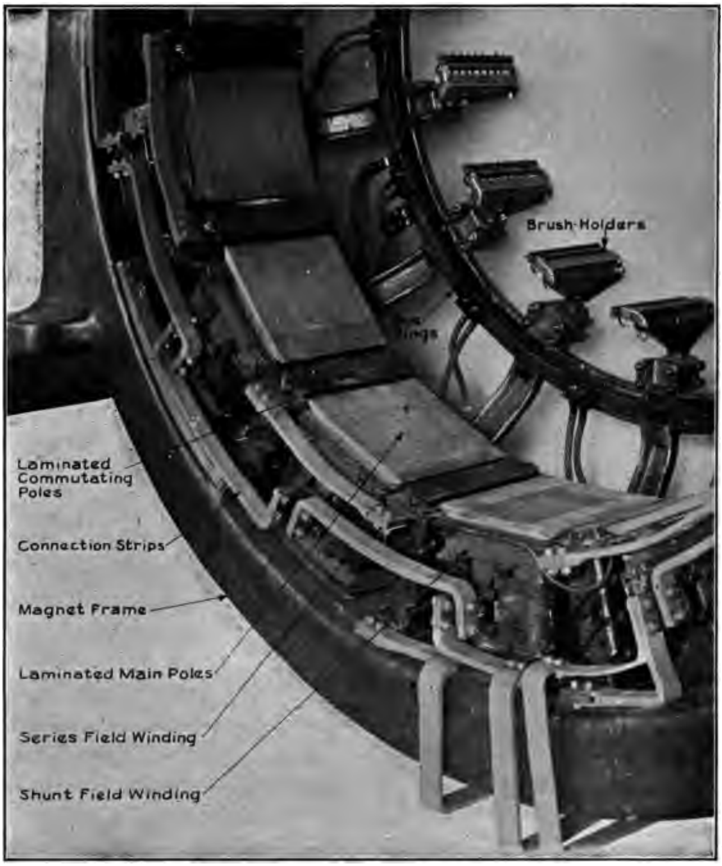


Fig. 3.—Large compound generator showing field construction.

Showing a section of the field structure of a sixteen pole, commutating pole, low voltage (250 volts), compound motor for roller mill service. Note the paralleling bus ring and cable connections for feeding parallel circuits in the commutating field winding. Note also cast commutating field coils securely anchored to the pole piece by bolts, and the bolted type of brush holder.

namely by drilling and tapping into the laminations directly to receive the frame bolts or by tapping into a steel bar inserted in the pole pieces.

The main field winding consists of a spool, wound with the series or shunt or a combination of the two windings, as shown in Figure 3. The spool itself consists of a sheet iron or copper body with flanges of insulating material such as wood, fibre or asbestos lumber. This spool is thoroughly insulated and is then wound with the shunt winding consisting of the necessary turns of small insulated wire. Entirely separated and insulated away from this shunt winding is the series winding which is made up of relatively few turns of heavy copper strips.

In some types of machines the spool body is omitted and the field windings are made upon forms after which the coils are thoroughly insulated and mounted directly on the pole pieces. *Instead of winding the shunt* and series windings one over the other on a single spool, some practice favors the separation of these windings, such as placing them side by side, for the purpose of better ventilation and on account of greater accessibility for repairs.

The commutating field is wound with the required number of turns of copper strips or heavy wire, similar to the series winding. In the case of large machines the commutating coils are generally cast or formed from copper bars pressed into shape. The windings may be mounted on a separate spool or directly upon the insulated pole piece.

The armature of the motor is illustrated in Figure 4. It consists of a cast iron or cast steel spider upon which the mild steel laminations are assembled and divided into sections by small spacer blocks provided for ventilation. The laminations are pressed together and held in place by the flange rings and through bolts. In some machines these laminations are assembled directly upon a key on the shaft. The windings are then laid in the slots, held in place by means of small wooden wedges and binding wire and then soldered directly into the slots in the commutator segments or to the risers fitted in the segments.

Ventilation in the armature is accomplished by means of the small block spacers as mentioned above and in special types, where forced ventilation is employed, by providing horizontal ducts in the armature core in which case the vertical air ducts are omitted.

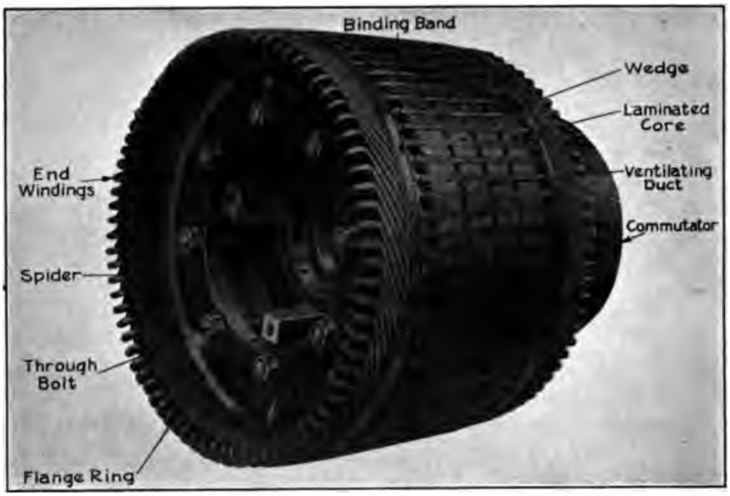


Fig. 4.—Rear end view of armature.

The commutator is made in the form of a rigid self-contained structure. A number of forged copper bars, slightly thinner at one edge than at the other are built up in the form of a hollow cylinder with mica plates between the bars. A steel hub with conical lips fitting into the conical seats or grooves turned in the copper bars is provided and the ends of the hub are drawn together by bolts. The commutator segments are completely insulated away from the shaft and hub by means of moulded mica washers. The complete commutator is forced on the shaft and held in place by a key. In some cases it is mounted on an extension of the armature spider.

Fig. 5.—Showing the assembled commutator and the individual parts before assembly. Note the conical seats on the spider and clamping ring fitting into the machined grooves of the assembled segments, insulated with mica.

ASSEMBLY PARTS

The brush rigging is supported from the magnet frame. The brush holder yoke is fitted with lugs to which the brush holder brackets are bolted. Brush holders are bolted or clamped to these brackets with all brushes connected to a common bus bar or to the brush holder bracket itself.

In other types of machines, the brush rigging is supported on the pillow block or bearing housing and in larger sizes directly by the base or foundation. The brackets and holders are supported as stated above.

The brush holder brackets are insulated from the brush holder yokes by fibre bushings and collars. The bus rings for connecting brackets of like polarity are supported by connecting strips or "ears."

The bearings are supported by pedestals bolted directly to the base or foundation or by end shields supported by the field frame. Where pedestals are employed, liners or shims of sheet iron are provided for adjustment. Bearings except in special cases are of the ring oiled type. These special cases refer to motors on board ship or mounted on movable machinery, where there is danger of spilling of oil due to tilting or rocking. Such bearings are usually of the waste packed type although ball or roller bearings packed in grease are sometimes employed.

The base is usually made as a rigid structure of cast iron. Sometimes I-beams or channel irons are used as supports. Bolt holes for foundation bolts are placed in the base where the unit is to be used for direct drive or geared connection. When belted, chain or rope driven, the bases are fitted with sliding rails unless an external tightening device is fitted.

TYPES OF MOTORS

Shunt Motors.—In a shunt wound motor one winding only is furnished on the main field spools to supply the entire excitation. This field is usually connected to the same power supply as that for the armature but the fields may be excited from a separate source if it is so desired. The speed regulation is obtained by an adjustable resistance in the shunt field current or by a resistance in series with the armature. Shunt motors have practically a constant speed at all loads.

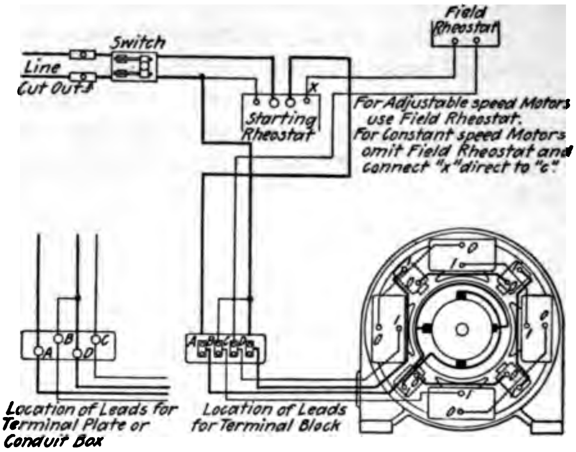
Compound Wound Motors.—Motors of this type are equipped with a shunt winding, as mentioned above and have in addition a series winding wound on the same spool with the shunt. The series winding is connected in series with the armature circuit and the field excitation is varied as the load on the motor changes. Compound or series windings are usually connected to assist the shunt windings but in some special work the series winding may be set to oppose the shunt; this arrangement being known as a differential compound motor. An adjustable resistance across the series winding is furnished to permit a change in the strength of the series excitation. The speed of compound wound motors drops as the load comes on.

Series Motors.—A series motor differs from the shunt and compound types just described, in that all of the excitation is supplied by a winding on the main spools connected in series with the armature. The speed changes with the load on the motor. Under maximum load the speed is minimum since the field is strongest. At no load and with constant voltage applied, the series motor will race or run away and thus a provision should be made when installing a series motor to guard against the removal of the load while voltage is being applied to the machine.

CONNECTIONS FOR MOTORS

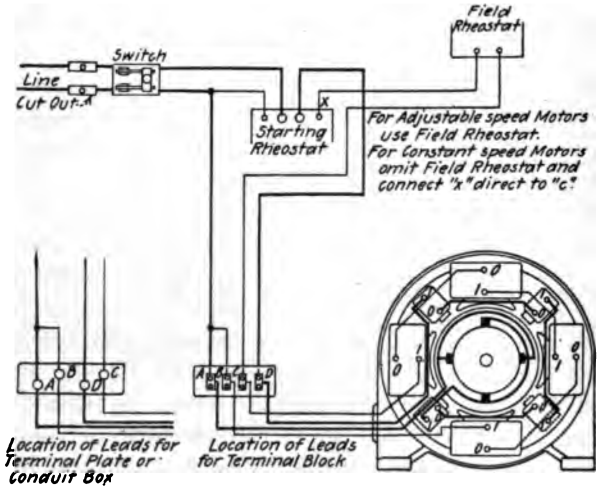
Standard connections for motors are shown below but no attempt is made to cover the many special or "freak" connections which are possible in wiring motors for service of a special nature. In each case a line diagram as well as a complete connection drawing is shown to enable the reader to see at a glance the general scheme of connections.

The diagrams show motors fitted with commutating poles



Motor Connected for Clockwise Rotation

FIG. 6.—Connections for commutating pole, four-pole, shunt motors.



Motor Connected for Counter Clockwise Rotation

FIG. 7.—Connections for commutating pole, four-pole, shunt motors.

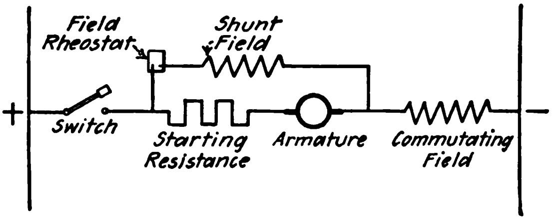
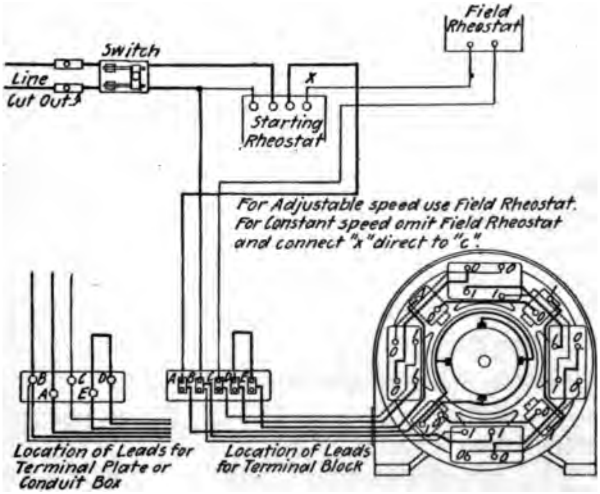


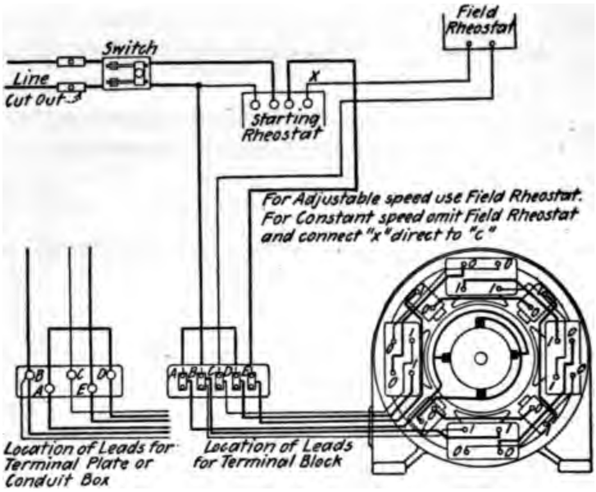
Fig. 8.—Sketch showing the connections for a shunt wound motor.



For Adjustable speed use Field Rheostat. For Constant speed omit Field Rheostat and connect "x" direct to "c".

Motor Connected for Clockwise Rotation

Fig. 9.—Connections for commutating pole, four-pole, compound motors.



For Adjustable speed use Field Rheostat. For Constant speed omit Field Rheostat and connect "x" direct to "c"

Motor Connected for Counter Clockwise Rotation

FIG. 10.—Connections for commutating pole, four-pole, compound motors.

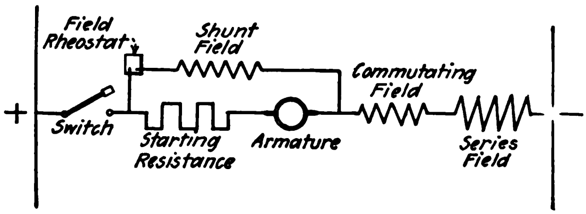
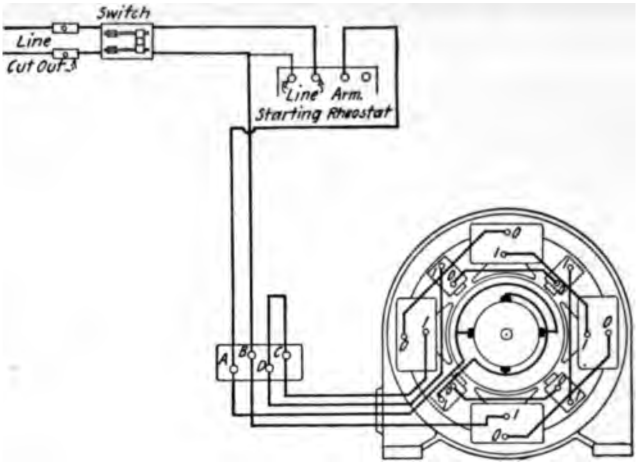
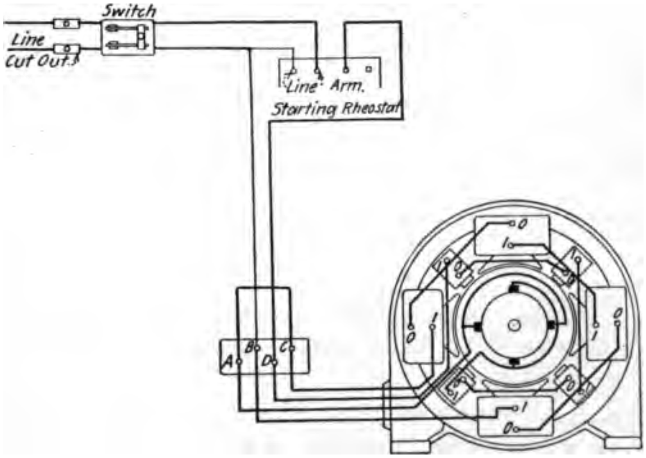


FIG. 11.—Sketch showing the connections for a compound wound motor.



Motor Connected for Clockwise Rotation

FIG. 12.—Connections for commutating pole, four-pole, series motors.



Motor Connected for Counter Clockwise Rotation

FIG. 13.—Connections for commutating pole, four-pole, series motors.

but the same connections may be used for motors without the poles.

The connections for a shunt wound motor are shown in Figures 6 and 8. For reversed rotation refer to Figure 7.

The shunt fields are connected in each case to permit full excitation of the field as soon as the switch in the line is closed and before the starting resistance has been cut out of the armature line.

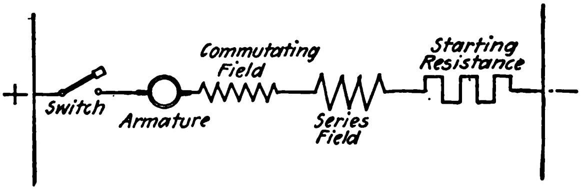


Fig. 14.—Sketch showing the connections for a series motor.

Figures 9, 10 and 11 show the connections for a compound motor with the addition of the series fields. In Figures 12, 13 and 14 are shown the connection for series wound motors.

USES OF DIFFERENT TYPES OF MOTORS

Shunt Motors.—Shunt wound motors are used where approximately constant speed is required from zero to full rated load, and in service of such a nature as to require very light starting torque. For example, shunt motors are used on fans, centrifugal pumps, small lathes and drills and compressors, where the load does not build up until the motor has practically reached its normal speed. Shunt motors should never be used for service such as that required of street car main motors, piston pumps working against a constant pressure, hoists and elevators. The use of shunt motors for driving machine tools is shown in Figure 15.

Two shunt motors mounted on the same shaft or coupled together mechanically and driving a common load will not divide the load equally and trouble due to overload of one or the other will result if such an arrangement is employed.

Motors built to be exact duplicates have a slightly different speed regulation and saturation curve with the result that one unit will drive the other as a generator and a heavy current will circulate between the two machines causing overloading of both. Two shunt motors may, however, be operated when coupled mechanically as mentioned, if the shunt fields are separately excited from some external source (not from the power bus supplying power to the armature).

Shunt motors will operate in parallel without trouble when connected to the same source of power and driving a common load, if the armatures are free to run at different speeds due to the absence of positive mechanical connection through the shaft or coupling. Shunt wound motors will not race or run away if the load is removed.

Summing up the above, shunt motors are used only when the starting duty is light and constant speed is required. Do not attempt to operate two motors on the same shaft if they are shunt wound.

Compound Motors. (*A*) *Cumulative.* Motors of this class are used where a relatively large torque is required at starting and where the conditions do not require a constant speed with changes in load. Anchor hoists, winches, compressors, elevators and mills for rolling metals furnish examples of service requiring compound motors.

Compound cumulative motors differ from shunt wound types in speed regulations since the compound motor drops in speed very appreciably from zero to full load. The compound windings may be so adjusted by use of shunts across the terminals of these windings that the drop in speed is not objectional. The effect of the compound winding may also be cut out by automatic devices which short circuit the series winding after the motor comes up to speed. It should be noted, however, that any weakening of the compound or series windings by shunts or short circuits, reduces the starting torque and the motor may refuse to start under load until the field strength is restored.

Compound motors will operate in multiple, driving a common load even if mounted on a common shaft or coupled together. This is a great advantage over the shunt wound types. Mechanical load may be thrown off without danger of overspeed or runaway with this type of motor as noted in the shunt types, but the rise in speed will be considerably higher than in the shunt type.

— MOTORS FOR MACHINE TOOLS —

TOOL	Direct Current Motors		
	Shunt	Comp.	Series
Bolt Cutter	✓		
Bolt & Rivet Header		20 40%	
Bulldozers		20 40%	
Boring Machines	✓		
Boring Mills	✓		
Raising & lowering Cross Rails on Boring Mills & Planers		40%	✓
Boring Bars	✓		
Bending Machines		20 40%	
Bending Rolls		40 80%	✓
Corrugation Rolls		20 40%	
Centering Machines	✓		
Chucking Machines	✓		
Boring, Milling & Drilling Machines	✓		
Drill, Radial	✓		
Drill, Press	✓		
Grinder-Tool, etc	✓		
Grinder-Castings		20%	
Gear Cutters	✓	20%	
Hammers-Drop		20 30%	
Keyseator-Milling-Broach	✓		
Keyseator-Reciprocating		20%	
Lathes	✓		
Lathe Carriages			✓
Milling Machines	✓		
Heavy Slab Milling	✓	20%	
Pipe Cutters	✓		
Punch Pressers		20 40%	
Planers		20%	
Planers-Rotary	✓	20%	
Saw-Small Circular	✓		
Saw-Cold Bar & I-Beam		20%	
Saw-Hot		20%	
Screw Machine	✓		
Shapers		20%	
Shears		20 40%	
Slotters		20%	
Swaging		20%	
Tappers	✓		
Tumbling Barrels or Mills		20%	

FIG. 15.—Motors for machine tools.

(*B*) *Differential Compound Motors.* Motors of this type are very uncommon as the shunt motor will operate with very little speed change and have a starting torque greater than that of the differential motor. In a few cases such as paper mill drive, a differential compound motor may be used to advantage as the speed may be held constant by proper adjustment of the series field.

Series Motors.—Series motors are used where the service requires very heavy starting torque and where practically constant speeds at all loads are not required. For example, they are used as street car main motors, or on electric locomotives, and on cranes and hoists for heavy service.

The mechanical load must be so attached to series motors that there is no danger of the loss of the load. A removal of the mechanical load where the applied voltage is constant, results in the racing or runaway of the armature and wrecking due to overspeed. Racing is caused by the loss of the field, since the field strength of a series motor is dependent on the current in the line.

Series motors may be operated in series or multiple without trouble. They have a fixed speed for each load and are not suitable for service where constant speed is required with variable loads.

The uses of series and compound wound motors for driving machine tools are shown in Figure 15.

INFORMATION TO BE SUPPLIED TO THE MANUFACTURER WHEN ORDERING MOTORS

The Purchasers of direct-current motors should consider with great care the class and type of machine required and in cases of doubt consult the representatives of electrical manufacturing concerns, who keep up to date data on the product of their companies. A motor may be ordered for a service for which it is not designed and in such cases satisfactory operation is never obtained. For example a motor of the open type of construction should not be placed where it would be exposed to cement dust, oil or water spray, acid fumes, turnings or chippings from lathes or chipping devices, smoke, etc. The Purchaser should take advantage of the experience of the manufacturer in placing motors for various kinds of service and if the following general questions are answered when the request for motor equipment is made, a better and more satisfactory service will always be obtained:

1. What is the average load required?

2. What overload is required and for what length of time is such an overload necessary?

3. What is the voltage of the circuit furnishing power to the motor? If the voltage is not constant, the maximum and minimum values should be given.

4. Does the motor start under load?

5. Is the load steady or variable? (Give when possible, nature of the load to be driven.)

6. Is the motor located any considerable distance from the generator or supply lines? Give distance approximately.

7. Is the motor belted, geared or direct connected to the load?

8. What is the diameter and face of the pulley to be driven if already installed?

9. What is the speed of the driven shaft?

10. What speed variation if any is required?

11. What is the distance between the center lines of the motor and the driven shafts if belted?

12. Is the belt to operate in a horizontal or vertical position? Give approximate operating angle of the belt.

13. Are sliding rails required or a belt tightening device?

14. If the motor is direct connected or geared to the load is a separate base required with the machine or is the extension of the base supporting the driven parts arranged to take the motor frame and bearings.

15. Is a coupling, pinion or pulley required and if so what size?

16. Do the motor bearings support any weight of the revolving parts other than the armature? State how much and give the location of the load with respect to the center line of the nearest bearing.

17. Is a fixed length of shaft extension required? Give length.

18. What direction of rotation is required (facing the commutator end).

19. Does the motor reverse?

20. What is the local condition under which the motor is to operate? State if damp or hot or both and if acid fumes, smoke, grit or oil vapors are present.

21. Does the motor operate where it is exposed to flying chips or shavings from steel or iron working machines.

22. Is the motor located where quiet operation is necessary.

23. What control is required? State whether armature or field?

24. Is the space limited in which the motor is to be installed? Give the approximate maximum length, height and width.

25. What temperature guarantees are required, if any?

26. Must the motor terminals have a special location? State where.

27. Does the motor operate on the floor, side wall or ceiling? Is a vertical type required?

28. Does the motor operate as a generator and if so are reversing switches required?

29. Does the motor require separate excitation?

30. Must weight of motor be limited?

31. Does the motor operate on board ship or under conditions in which it is liable to be suddenly moved or tilted out of its ordinary operating position?

32. Is a flexible coupling necessary?

CHAPTER II

TYPES OF GENERATORS AND THEIR USES

TYPES OF GENERATORS—STANDARD ELECTRICAL CONNECTIONS FOR GENERATORS—USES OF DIFFERENT TYPES OF GENERATORS—INFORMATION TO BE SUPPLIED TO THE MANUFACTURER WHEN ORDERING

The construction of the direct-current generator is exactly the same as that of the direct-current motor briefly described in the preceding chapter. In fact the generator can be operated as a motor or vice versa, by simply changing the connections as covered later in this work, in Chapter IV on the "Starting and Operation of Motors."

The uses for which the various types of generators are best suited are given with the view of acquainting the operator or purchaser with the qualifications which each type of machine possesses to fit it for a particular duty. Great care should be exercised in the selection and the information furnished to the manufacturers, as given later, when ordering.

TYPES OF GENERATORS

Shunt Generator.—In a shunt generator, the field winding is connected in multiple with the outside connecting circuit, so that when the outside circuit is open, the field magnet coils receive the entire current supplied by the armature but when it is closed, the current through the field circuit depends upon the resistance of the field circuit as compared with that of the outside connecting circuit. By connecting a rheostat or adjustable resistance in series with the field winding, a greater or less amount of current may be permitted to pass through the field coils at any one time and the voltage of the machine is thereby controlled.

Fig. 16.—Field construction of compound wound generator with commutating poles and compensating windings.

Note lifting screws in magnet frame feet for air gap adjustments, ventilated series winding, and the compensating winding supported in the main pole faces, connected by copper strips bolted in place—the copper connection strips being separated from each other by fibre washers and insulated through bolts. The compensated winding is connected in series with the commutating field winding and is provided to prevent the distortion of the main field flux and to insure perfect commutation.

Series Generator.—In a series generator all the current that is produced by the armature passes through the field winding and therefore the field winding must be in series with the outside circuit. For regulating the voltage of a series generator, it is customary to connect an adjustable resistance, called a rheostat, across the entire field winding; by varying the resistance thus introduced, more or less current is shunted from the field coils and the number of lines of force in the field thereby changed.

Compound Generators.—In compound generators, both series and shunt field windings are employed to produce a combination of their characteristics. The characteristic curves show that in a generator with a series field winding an increase of current in the connecting circuit, such as would result from lowering the resistance of the circuit, causes the machine to develop a higher voltage; whereas in a generator

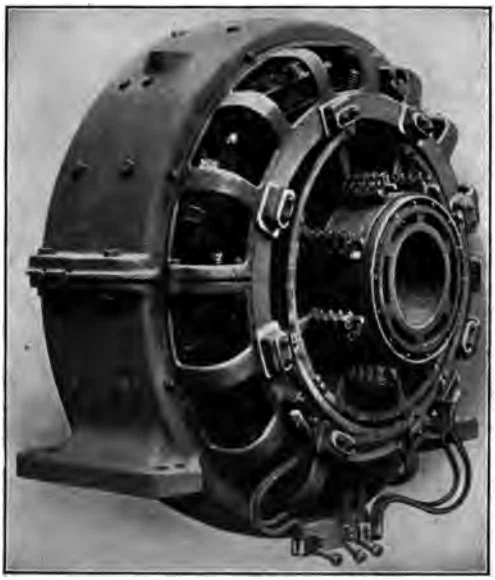


Fig. 17.—Compound wound, direct current generator.

Built by the Westinghouse Electric Manufacturing Co. Note the edgewise series field coils and open construction for ventilation.

with a shunt field winding, conditions producing an increase of current in the outside connecting circuit tend to reduce the voltage. In a compound wound generator there are both a series field winding and a shunt field winding acting simultaneously, and the ampere turns in the one are so proportioned to those in the other that the load or current conditions in the outside connecting circuit which would cause the one winding to produce a low voltage will at the same time cause the other winding to produce a high voltage and vice versa. The combined result of the two field windings is, therefore, to supply a practically constant voltage at all loads.

Three-wire Generators.—A 3-wire generator is intended to supply current over short distances to a low-voltage 3-wire system of distribution. There are three types of 3-wire systems employed, the Edison system employing two 2-wire generators, the 2-wire generator and balancer set and the 3-wire generator.

In the Edison 3-wire system, two generators are connected in series with a neutral wire tapped in between. Connecting either between the positive wire of one machine and the neutral or the negative wire of the other machine and the neutral will give just one-half the voltage which can be obtained by connecting across the positive and negative wires.

A 3-wire system of the above type requires the continuous operation of both generators. Another arrangement is sometimes employed whereby a single large generator furnishes the voltage between the outside wires; a small motor generator balancer set is connected across the outside wires and the neutral wire is led from a point between the two units of the motor generator set. The machine of the balancer set on the side having the lighter load operates as a motor and drives the other as a generator. This (for the time being) generator supplies current for the excess load on the other side and thus automatically balances the system.

The 3-wire generator still further reduces the initial cost and the expense of operating a 3-wire system, because there is only one machine to be purchased instead of two or three and there is less maintenance because there are fewer parts to be cared for. There is also a higher efficiency because one machine has smaller losses than any greater number of equal total output, and less floor space is required.

Three-wire generators are so arranged that a third or neutral line is brought out midway in potential between the positive and negative leads, thus providing for load at half of the generator voltage. This mid-voltage point is derived by connecting a reactance coil, known as an autotransformer, across the armature winding, the neutral line being connected to the middle point of the autotransformer. Connections between the autotransformer and the revolving armature are made through collector rings which have properly spaced taps to the armature winding. These connections are shown diagrammatically in Fig. 17A. This diagram shows the complete circuit for a load on the positive side, the current path being from the load through both legs of the autotransformer to the collector rings, then through the armature winding and commutator back to the load. The core of the autotransformer is magnetized by alternating current obtained from the collector rings. The direct current in the neutral wire divides between the two halves of the autotransformer winding equally and in opposite direction, thus producing no magnetic effect. The illustration referred to shows only the diagrammatic arrangement of the windings and should not be referred to for any actual mechanical connection. The autotrans-

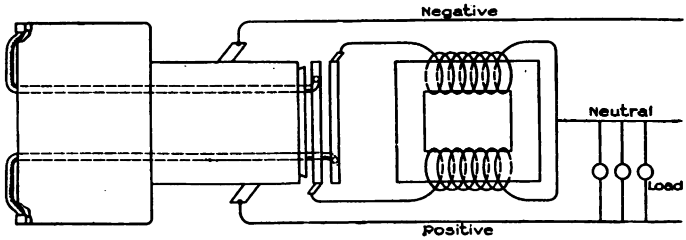
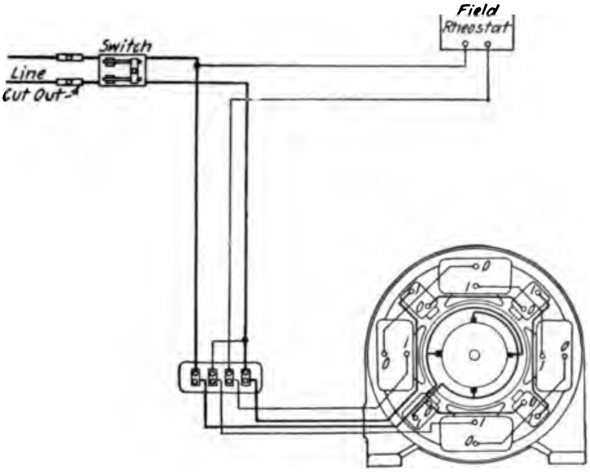


FIG. 17A.—Sketch showing connections for a three-wire generator loaded on positive side.

former itself consists of a laminated core with suitably insulated winding immersed in a cast iron tank of special insulating oil.

CONNECTIONS FOR GENERATORS

The diagrams given below show the usual standard connections for generators as used in common practice and no attempt is made to cover special conditions. An inspection of the line diagrams will show at a glance the general scheme



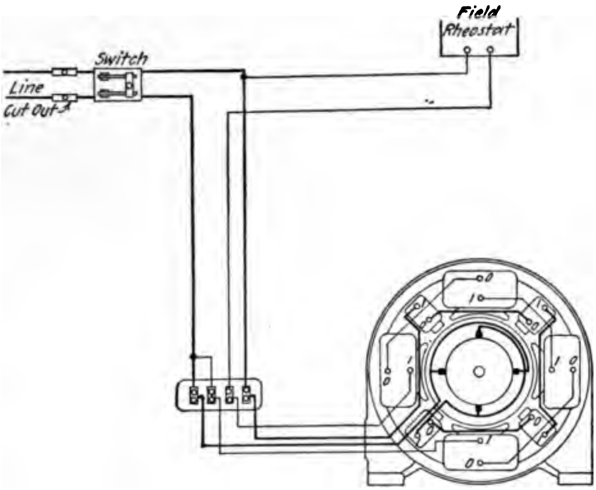
Generator Connected for Clockwise Rotation

FIG. 18.—Connections for commutating pole, four-pole, shunt generators.

of connection while an examination of the main diagrams will show all of the details of wiring. The generators shown are equipped with commutating poles but the same diagrams apply to machines without such windings.

Figures 18, 19 and 20 show the connections for shunt-wound generators. Figures 21, 22 and 23 show connections for compound-wound generators.

Each diagram shows a single unit. An article on the connections as employed in parallel operation will be found in Chapter V covering "Starting and Operation."



Generator Connected for Counter Clockwise Rotation

FIG. 19.—Connections for commutating pole, four-pole, shunt generators.

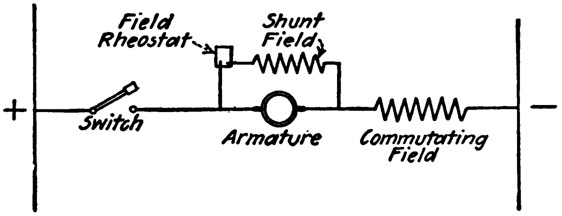
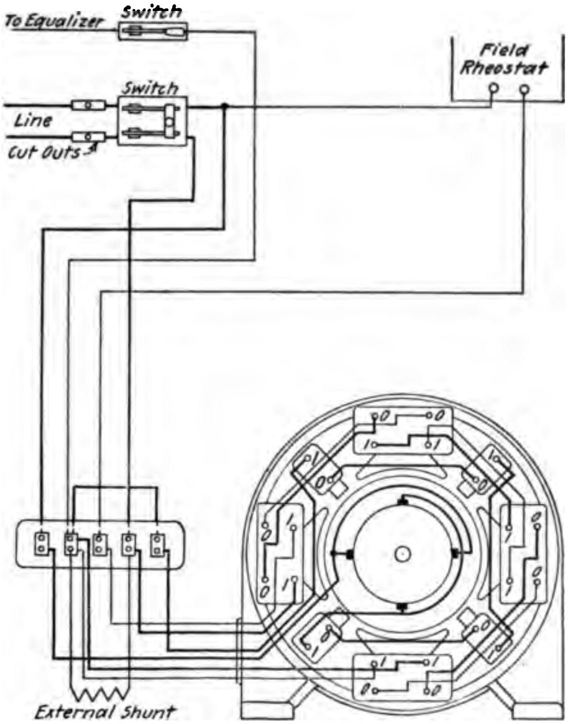
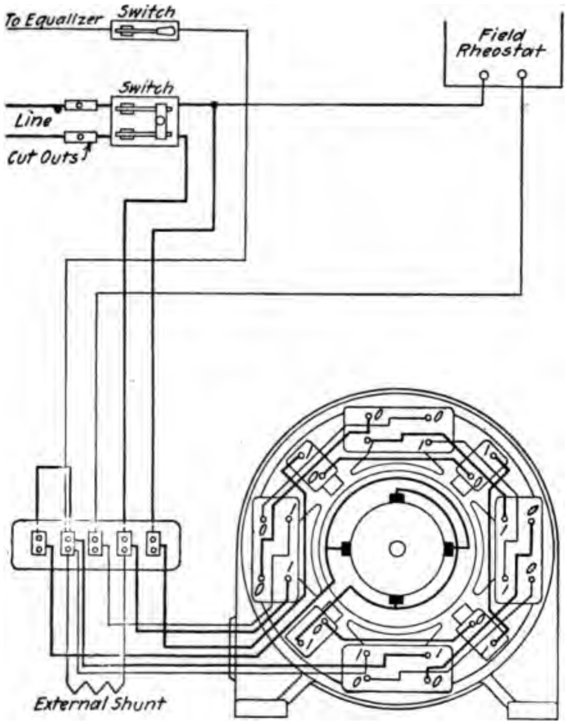


FIG. 20.—Sketch showing the connections for a shunt wound generator.



Generator Connected for Clockwise Rotation

FIG. 21.—Connections for commutating pole, four-pole, compound generators.



Generator Connected for Counter Clockwise Rotation

FIG. 22.—Connections for commutating pole, four-pole, compound generators

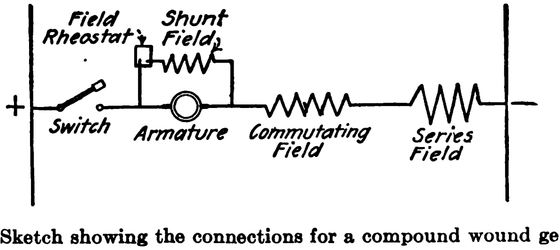


FIG. 23.—Sketch showing the connections for a compound wound generator

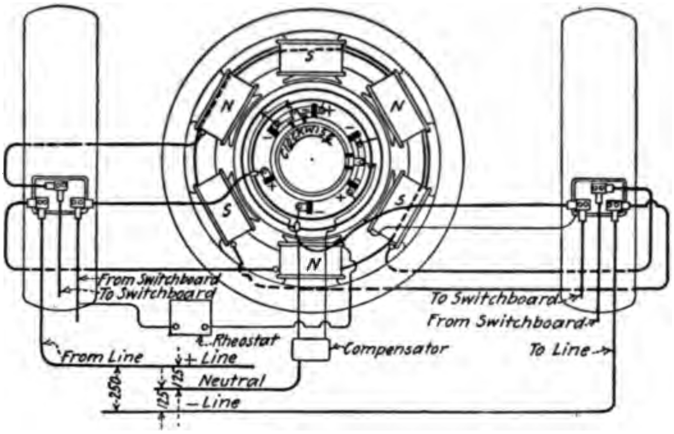


Fig. 24.—Connections for three-wire generators, compound wound, clockwise rotation.

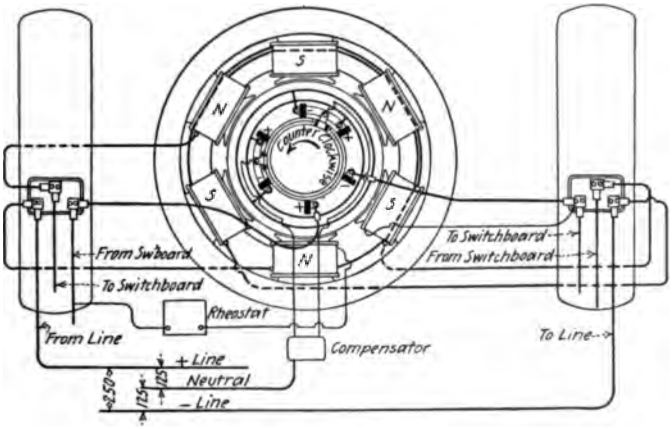


Fig. 25.—Connections for three-wire generators, compound wound, counter clockwise rotation.

Figures 24, 25 and 26 show the connections for 3-wire generators. Where the generators are compound wound, the series fields are split with all north poles on one side of the armature and all south poles on the opposite side. Two equalizers are required when 3-wire generators operate in parallel.

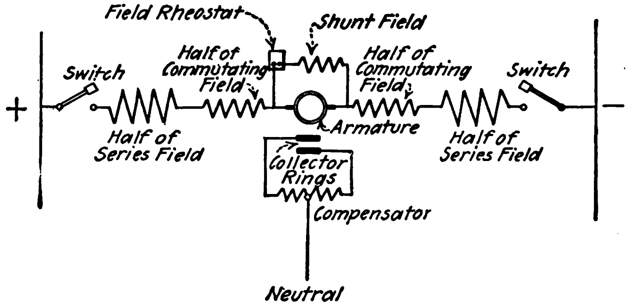


FIG. 26.—Sketch showing the connections for a three-wire generator with a compensator.

USES OF DIFFERENT TYPES OF GENERATORS

Shunt Generators (*Self-excited*).—Shunt-wound generators, self-excited, are used for service when the load remains unchanged for long periods of time. Large direct-current stations, electrolytic plants, furnaces, electrochemical equipments, and exciter plants furnish examples of the applications of generators of the shunt type. It should be noted, however, that the voltage as well as the current load must be approximately constant. Under such conditions parallel operation of self-excited shunt generators is satisfactory and once the load is properly divided by use of the field rheostat no further attention is required excepting an inspection of the meters connected to a machine placed in service with cold fields. Such a machine will drop its load slightly due to the increased resistance of the fields as a result of heating. When the temperature of the fields has reached a constant value no further attention is required.

Shunt Generators (*Separately Excited*).—Shunt-wound generators used in services where the voltage change is 20 per cent. or more of the normal rated voltage, should be excited from a source of power entirely separate from the circuit to which the armature is connected. Separate excitation is needed for example in charging batteries where at the beginning the very low voltage and the heavy amperage in the armature circuits would produce very unstable conditions in the generator and result in a dropping of the load on account of the loss of voltage. The same conditions would be met when the generator is being used for the purpose of boosting the voltage of a system by running the armature in series with the generator furnishing power.

For example, use separately excited generators for services as follows: Battery charging, boosting, Ward Leonard systems (*i.e.*) (where the voltage is carried through zero from maximum to minimum, positive and negative, for reversing purposes and speed control of motor by armature or voltage control) and parallel operation of shunt-wound generators with fluctuating loads.

Compound-wound Generators.—This type of generator is the one most commonly found in practically all lines of service, including that previously mentioned for shunt-wound units, provided in the latter case that hand regulation is resorted to for control.

Compound-wound generators are used where a constant voltage supply is required with a continuous change in load. Generators furnishing power for pumps, fans, blowers, dredges, ship propulsion (except in the case of Ward Leonard Control), and general power will in practically all cases be found to be compound wound.

Parallel operation of compound generators is automatic when the units are once adjusted and very little attention is necessary to keep the load properly divided between the units in operation.

The series windings may be cut out and the generators will then operate as shunt-wound units but care should be taken to prevent undue heating of the shunt fields if full voltage is generated with the shunt winding without the assistance of the series fields.

Series Generator.—Series generators are used only in cases where boosting of the voltage is required, such as at the end of a long railway feeder carrying heavy current loads. Care should be taken to equip such units with protective devices against overspeed as the failure of the power driving a series generator results in the instantaneous operation of the generator as a series motor with practically no load. Such a condition will wreck the unit from overspeed if it is not provided with a protective device.

Mechanically operated speed-limiting switches are mounted directly on the shaft extension, being equipped with a tripping lever operated by centrifugal force arranged to open the main line circuit breaker when the speed of the machine reaches a value approximately 15 per cent. over the normal rated speed.

In some cases an electrical speed-limiting device is employed consisting of a small magneto type generator driven directly by the main shaft and arranged so as to trip the main circuit breaker when the voltage which it generates reaches a fixed value.

Three-wire Generators.—Generators of the 3-wire type are used when the nature of the load is such as to require two different voltages, for example 125 volts for lights and 250 volts for motors. When the load can be balanced between the two sides of the system within 25 per cent., the compensator type of 3-wire generator is employed. Except in special cases where the unbalancing is more than 25 per cent., balancer sets are recommended or the Edison 3-wire system.

Three-wire generators operate satisfactorily with motor and lighting loads and also for elevator and hoist service using the high voltage for motor drive. On electrolytic work 3-wire machines are used to only a limited extent as operators complain of shock from the high voltage when accidental contact is made. The regulation between the two sides of the system is approximately 2 to 3 per cent. of the outside wire voltage and while the variation is not noticed in most lines of work, where very close regulation is required and it is not practical to throw loads from one side of the system to the other for balancing, the 3-wire generator cannot be used. In Edison 3-wire systems the voltage remains constant and full output is obtainable from either side. Balancer sets are designed to take care of a fixed percentage of unbalancing.

Fig. 27.—A 100 kilowatt, 250/125 volt, 260 r.p.m., three-wire generator manufactured by the Allis-Chalmers Co.

On all of the above systems there is a two-thirds saving in copper mains effected because the current is being transmitted at double the voltage usually employed with the 2-wire generator for the same service. For the small plant, compensator 3-wire generators are recommended, particularly where the generators are engine driven or slow speed as the compensator for deriving the neutral can be made a part of the generator. In larger units of 500 kilowatts and above, balancer sets are recommended.

INFORMATION TO BE SUPPLIED TO THE MANUFACTURER WHEN ORDERING GENERATORS

The choice of a generator for a given service is best made after making a careful survey of the actual working conditions. A great deal of trouble and expense may be saved in case the purchaser is not familiar with general practice and the uses of different types of machines by consulting a competent representative of the manufacturers of electrical machinery.

Each type of generator has its special fields of use and it is not always safe to place a generator in service without giving due consideration to the conditions of its service. The following questions will suggest points to be brought out when a request is made for quotations, in ordering a generator from the manufacturer:

1. What is the voltage required? Give the average as well as the maximum and minimum values.
2. What is the nature of the load—general power, lights, elevators, hoists, battery charging, electrolytic work, railway or mining?
3. What is the maximum swing or peak?
4. What kind of a prime mover is employed? If a water wheel is used what runaway speed is required?
5. What temperature guarantees if any are required?
6. What are the no-load and full-load voltages of machines already installed if the generator is to operate in parallel?
7. Are the generators already installed equalized on the positive or the negative side?
8. Is the generator to be exposed to grit, dust, oil, grease or acid fumes? Is the generator room hot or damp or both?
9. Is a base required or does the generator frame rest on an extension of the prime mover base?
10. Is the armature mounted on an extension of the engine shaft? Must the bearings be furnished with the generator?
11. What location of terminals is required? Are special sized lugs necessary? Give sizes.
12. Must the generator clear the floor or is the construction of a pit beneath it possible?
13. Is the generator belted, geared, or direct connected to the

prime mover? Give the size of the pulley and speed if the generator is belted and a driving pulley is already installed.

14. Are sliding rails required or is a belt tightening device necessary?

15. Is the machine to be of the 3-wire type?

16. Is the voltage range over 20 per cent. of the normal and if so what is the voltage from which separate excitation may be obtained?

17. Is the generator to be required to operate as a motor? If so, are reversing switches necessary on the frame of the machine or on the switchboard?

18. Is a line resistance necessary? Give the machine number, ratings and name of manufacturer of generator already installed.

19. What is the direction of rotation facing the commutator end?

20. Do the generator bearings take any load other than the armature weights? State how much if any.

21. Is a coupling, pulley, pinion or special shaft extension required? Give details.

22. Are overspeed devices necessary?

23. Must the generator operate without noise?

24. Must the generator meet special space requirements? Give limits.

25. Does the generator operate on board ship or under conditions where it is liable to be suddenly thrown out of its normal operating position?

CHAPTER III

ERECTION AND ASSEMBLY OF DIRECT-CURRENT MOTORS AND GENERATORS

STORAGE—UNPACKING—LOCATION—FOUNDATIONS—HANDLING—USES OF SLINGS—INSPECTION—ASSEMBLY—ERECTION—PRESSING THE ARMATURE ON THE SHAFT

ERECTION AND ASSEMBLY OF DIRECT-CURRENT MOTORS AND GENERATORS

The proper and efficient operation of motors and generators depends in a large measure upon their erection and assembly. Good results cannot be obtained where the machines are carelessly assembled and erected in unsuitable locations and upon faulty foundations. Poorly erected sets are a cause of constant trouble and manufacturers have found that in a great many cases where the proper results have not been obtained, the defects were directly traceable to the poor judgment of those responsible for assembling and erecting the machinery. Local conditions, of course, often demand special instructions in regard to the foundations, but in general the rules and methods described here, are those in use in the best practice and recommended by the manufacturers.

STORAGE

When a motor or generator must be stored before being put into service it should be put in a dry place, well sheltered. The original crates in which the machine and its parts were shipped should not be opened until everything is in readiness for installing the unit.

UNPACKING

The greatest possible care is necessary in unpacking and handling the machines in order to avoid damaging the windings and other conducting parts.

Take particular care in removing the crates, that the insulation of the field or armature coils is not damaged by the points of nails, or by the tools being used.

Should any slight defects be caused or noted during unpacking, such as damaged insulation, they should be repaired before the generator is assembled, as described in the chapter on "Tests and Repairs" on Page 247.

LOCATION

The following conditions must be met in arranging the motor or generator sets in order to insure satisfactory operation.

Moisture.—The machines should be placed in a dry place and must be protected from moisture of any kind. Steam must not be allowed to escape around them from leaking glands, pipes and fittings, and moisture condensing on pipes or on the ceiling, or leaking from them, must be caught by a shield and prevented from falling on the units. Machines to operate under moist conditions are usually designed with a special view to meet the requirements of such service. In order to fit an ordinary machine not so designed, for operating where there is a great deal of moisture, the armature and fields should be heated, dipped and baked as described on Page 248 in Chapter VIII.

Ventilation.—The arrangement should be such as to provide for a constant supply of cool air. The question of ventilation of electrical machinery is a very important one and directly affects the capacity of the machine. Machines running in hot places will show a decided falling off in load capacity as compared with those located in cooler places.

The ventilation however should be as effective as possible and as cool a running temperature secured as is consistent with the proper protection from dirt and moisture. In one case on record, very cool air was secured for ventilation of a generator from an open window nearby. A mica plant was situated in the neighborhood and in a short while, a great deal of sparking was developed on the commutator of the generator due to fine mica particles getting in between the commutator segments and the brushes. A case of brush wear recently resulted from a large volume of cement dust from a concrete mixer, blowing in through an open window. Such occurrences as these illustrate the necessity of using care in securing ventilation so that cool air is not procured at the expense of bad operating conditions.

The length of life of the machine will also be materially increased if the proper attention is paid to securing good ventilation.

Dust, Dirt, Acid Fumes, Etc.—The machine must be protected from dust, dirt or lint of any character. When it becomes necessary to do construction work of any nature in the immediate vicinity, care should be exercised to see that the sets run under as clean conditions as possible, covering usually with a piece of clean canvas or oil cloth. Acid fumes or corrosive gases such as chlorine, etc., must be excluded from the station.

Accessibility for Repair and Inspection.—The location of the set and the surrounding equipment should allow easy access to the commutator and brush rigging for cleaning and inspection.

FOUNDATIONS

The foundation must be so firm that the generator or motor will operate at full load without appreciable vibration and should be capable of sustaining the weight of the machine without undue settling. The bases furnished with modern machines except in very special cases, such as portable substations, are not designed to be self-supporting and therefore the foundation should be made so as to support the base under all points.

Substantial concrete foundations should be built for all machines. The area of the base should be ample, and the footings carefully laid and bonded into the body of the masonry. The kind and depth of the footing obtained depend largely upon the nature of the ground upon which it rests, and can best be determined by the engineer in charge of the work.

For a direct-connected generator, a footing, common to the engine and generator, and extending under all, should be built to interlock all foundations, and make them one substantial unit. In fixing the spread of the footing for the foundation, one and one-half times the width of the foundation base should be allowed if on hard gravel, and twice that width if on sand or stiff clay; if on soft clay, a layer of concrete should be spread beneath the footings.

Footings are usually built as follows:

First.—Rough stones laid in cement.

The stones should be laid flat as far as possible, and continuous joints avoided.

The largest stone should be laid at the bottom, the footing being laid up in courses.

All stone should be thoroughly wet before bedding, and all interstices should be well filled with cement.

Second.—Hard brick laid in cement.

The courses should be laid as in the case of stone, using only hard-burned and well-shaped brick, thoroughly wet before laying.

Joints should be made not less than one-quarter inch thick, filled with cement, each course being flushed with thin cement.

Third.—Concrete made of one part Portland cement, 4 parts broken stone or brick, and 2 parts of sand, all by measure.

This concrete should be built up in layers of not less than six inches nor more than twelve inches in thickness and should be rammed until the moisture or water appears on the top.

The pieces of broken stone should not be more than two inches along any one dimension and a portion of them should be not over half that size.

The depth to which the foundation should be carried depends upon the nature of the ground, but the footing should not be less than eighteen inches thick.

If it is necessary to build a foundation in freezing weather, special precautions should be taken. Salt may be added to the water, or the water and sand may be warmed just before it is used. Should the ground upon which the footing is to be built be frozen, it should be thawed out before work on the footing is commenced. These foundations should be allowed to set for at least two or three weeks before the machine is placed upon them.

The foundation proper rests on this footing and is thoroughly bonded to it. It may be built as is the footing, of stone, brick or concrete and the same method of laying the courses should be pursued as has been described for the footing. The sides of the foundation are usually given a batter of one and one-half inches to the foot.

The top of the foundation should be leveled off carefully and finished to receive the capping as here described.

Foundation bolts should be located accurately, as shown on the foundation plans, and a space of at least an inch should be left all around them to allow for adjustment after the frame, rails or timbers are in place; the holes should then be filled with thin cement or grout. No holding down bolts are necessary for motor generator sets which have bases and no bolts are provided in the bases.

Motors and generators may be supported by parallel walls or I-beams under the sides of the base if rectangular foundations are not desirable. In this case reinforced concrete or I-beams of sufficient stiffness should be run from wall to wall as a girder under the center line of each bearing to take the load of the rotor. Such support is necessary as cast iron bases are not rigid enough to support their load without yielding too much and thus causing misalignment of the parts of the machine.

HANDLING

When erecting apparatus and especially in the case of large units, methods of handling and transportation are of prime importance. Each piece of apparatus must of course be handled with reference to its special construction. The following observations, however, apply to the handling of apparatus in general

The Rotor.—The rotor must never be lifted or supported by the collector rings or commutator, or by any part of the end windings or binding bands, nor should the rotors of three or four bearing sets, whose separate units are formed by couplings, be lifted by placing slings under the shaft extensions at the ends only. A sling should be used near the coupling also, thus preventing injurious deflection and undue strains.

The only safe method of supporting the rotor while either moving or stationary is by slings or blocking under the shaft. In lifting large diameter direct-current armatures by means of short slings which may bear against the end windings or the commutator, the slings should be forced apart by a spreader resting on top of the armature so that the slings approach the shaft vertically, thus bringing no pressure on the end windings. The commutator clamping ring may in some cases be protected against pressure from the slings by means of a block of sufficient thickness placed inside the ring against the bolt heads.

The Magnet Frame.—Where there are eye bolts or lugs on the upper half of the magnet frame they are provided for lifting the complete magnet frame, with poles and spools assembled. Both halves of the frame bolted together, may be laid down horizontally by means of these eye bolts or lugs, but they must not be used for lifting the complete machine, or the frame and armature, without additional support under the shaft extensions or bearing housings.

The weight of the armature and magnet frame should not be allowed to rest on the base without substantial support directly under the points where the weight comes.

THE USE OF SLINGS

It is important to have a good knowledge of the correct use of slings in order to secure good results in the handling of heavy parts.

Bases with pillow blocks attached are usually lifted by hitching about the pillow blocks as shown in Figure 32.

A long base or one of light section should not be lifted by means of the pillow blocks until a strut of timber has been secured between the tops of the pillow blocks, to prevent them from collapsing when lifted. See Figure 32.

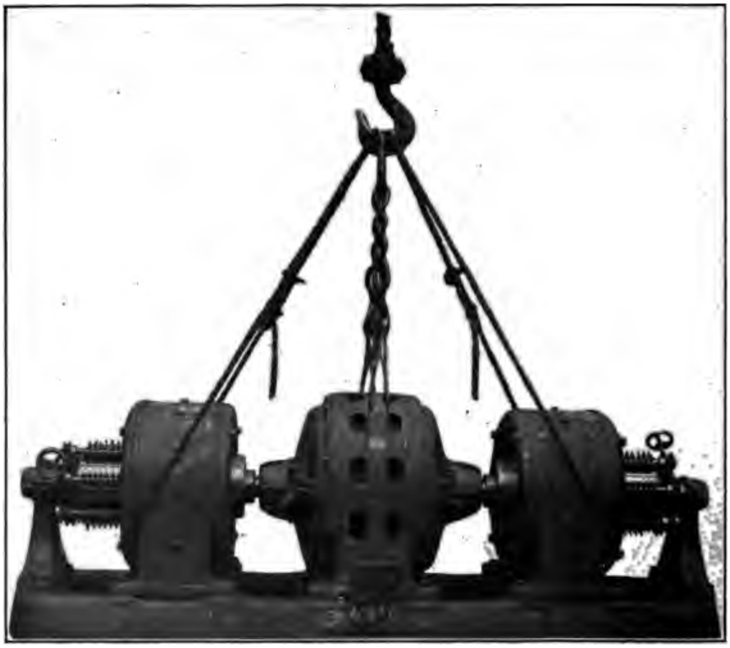


Fig. 28.—Lifting three unit set (right way).

As long a sling as possible should be used to prevent undue stress in the slings themselves, since the stress increases rapidly with an increase of the angle between the slings. The proper application of a sling is shown in Figure 28.

Wherever eye bolts are provided in frames or machine parts for lifting, the direction of the pull of the sling on the eye bolt must always be along the center line of the eye bolt, otherwise

Fig. 29.—Lifting three unit set (wrong way).

In this case there are a number of sharp corners unprotected while the manila rope sling passes through the loop of the wire cable, and the arrangement of the outside slings does not permit of an even distribution of the load.

a bending stress is produced which may fracture or bend the eye bolt, even under a load that it should easily carry if applied properly. Where the proper pull on the bolt cannot be obtained, a spreader must be inserted between the slings. The spreader must be secured so that it cannot slip out of position.

Fig. 30.—Hitch with one cable equalizing strain on four parts.

Fig. 31.—Hitch with unequal strain on two cables.

When lifting the top half of a direct-current machine, the sling is usually passed around the top frame between two spools. Care is necessary to prevent slings from pressing against the spool windings or veneer flanges and damaging them. A thick soft pad of canvas, leather, or similar material can be often used to advantage when making such lifts. It must be understood however that this is not a certain preventa-

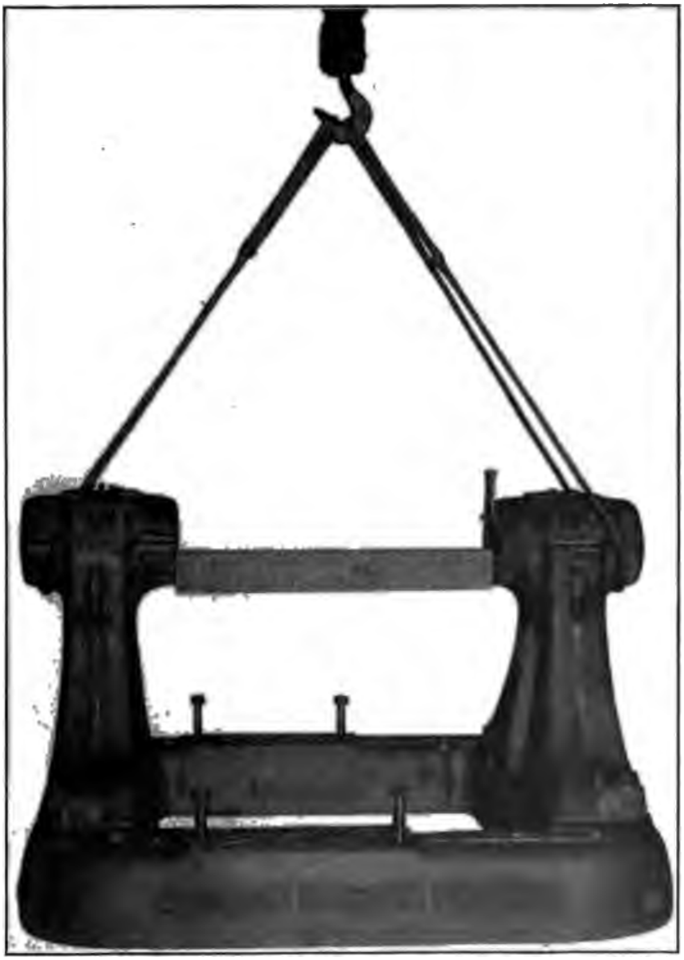


FIG. 32.—Method of lifting base and standards.

Frequently a base and standard are lifted and no provision is made for any lateral strains that may occur, tending to place an unnecessary strain on the bolts fastening the standards to the base. When such a lift is to be made, a piece of timber should be placed between the bearings to relieve the strain, as shown.

tive against damage. Unless great care is taken, spools may be damaged by the slings rubbing against them when turning the frame from a horizontal to a vertical position.

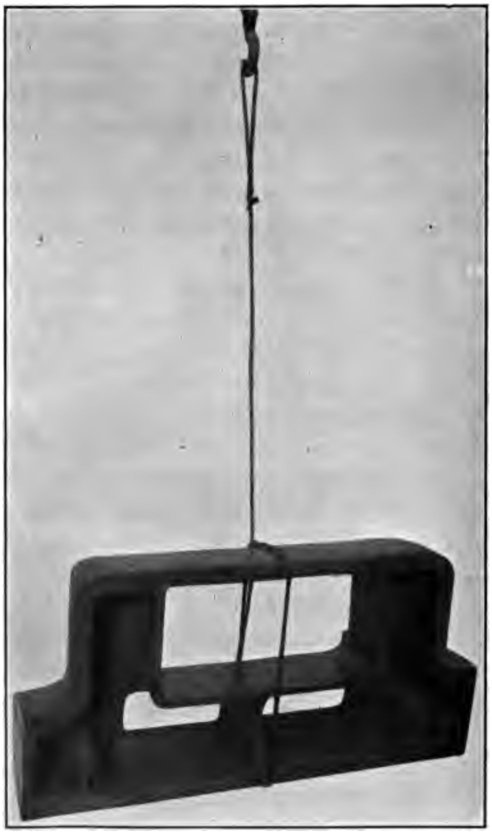


Fig. 33.—Single cable sling for lifting base.

INSPECTION

Before starting the assembly of a new machine a careful inspection should be made to see that none of the parts have been damaged since leaving the factory. Frequently slight defects, such as damaged insulation, can easily be repaired before the machine is assembled. During erection every precaution must be taken to guard against damaging the insulation or small projecting leads, because the construction of these parts is such that they will not stand the strain incident to lifting.

FIG. 34.—Double cable sling for lifting base.

General Rules.—In assembling generators and motors, the following general rules apply.

1. Clean carefully all joint surfaces and (except electrical connection joint) coat them with a thin layer of oil before fitting them together.

2. Draw the bolts up tight and be sure that the surfaces come together. This is especially important in the case of the pole pieces and halves of the magnet frame.

3. See that the bearings are perfectly clean before assembling and that no grit or dust gets into them when the armature is being put into place.

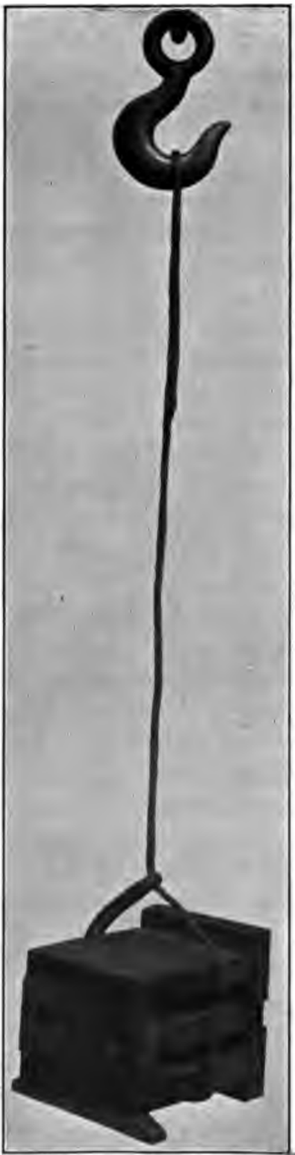


FIG. 35.—Double cable sling lifting load (right way).

Showing the use of protective pads to prevent damage to the laminations of the pole piece.

FIG. 36.—Single cable sling lifting load (wrong way).

4. Be careful that the field spools or armature windings do not strike on sharp corners, which would damage the insulation.

5. Observe carefully the markings of all parts and in assembling see that they correspond.

METHODS OF SHIPPING

In general practice direct-current motors and generators are shipped by the manufacturers in three forms. In relatively small units the machines are shipped completely assembled. The larger units may be shipped with the armature and frame separate or in some cases with the armature and frame separate and the frame divided horizontally into halves. These methods of shipping the machines must, of course, be changed to suit the requirements of special conditions. In some cases with the larger units, practically the entire machine must be disassembled for the shipping. In our discussion we will eliminate the problem of erection in the case of the small units for here since they are completely assembled when shipped the only requirements to be met will be those in regard to their location and foundations.

ERECTION

The foundation should be thoroughly cleaned before the machine is set upon it. Bases of all sets, whether shipped assembled or disassembled should be carefully leveled before being grouted in.

In large machines shipped disassembled the base should be grouted in and given sufficient time to "set hard" before the stators and pillow blocks are put in place. In these large units this work should be done under the supervision of one who is expert in lining up machinery. The pillow blocks should be bolted down and doweled to the plates and the magnet frame should be bolted down but not doweled until the air gap has been adjusted and good end play obtained with the machine running under load. The air gap is adjusted by moving the frame horizontally on the sole plates until the gap is equalized at each side of the armature and then by inserting or removing shims under the feet until the gap at the top and bottom is similarly equalized. The raising screws, if provided in the feet, facilitate this vertical adjustment. End play is adjusted by moving the magnet frame horizontally along the line of the shaft.

For machines equipped with separate cast iron bases, the bases should be located in the proper position and temporarily supported on iron wedges driven under the pillow block and magnet frame points of support. Care should be taken that the wedges are evenly and closely spaced and driven to divide the weight properly to reduce strains in the cast iron base, and that the inside flange of the base is wedged up under the pillow blocks to prevent their leaning in or out and reducing the end play. The base should be carefully leveled, using an accurate straight edge and good level on the machined surfaces.

The base should be grouted by building a low dam around the inside and outside and floating in a mixture of one part Portland cement to one part of clean sharp sand to a height of one-quarter inch above the lower face of the base. The wedges should not be removed until the grouting has set. Deep grouting should not be put in owing to the difficulty of subsequently removing the base if at any time desirable.

The machined surface of the base, the pillow blocks, and the end of the magnet frame feet should be cleaned before assembling. The heights of the pillow blocks and magnet frame are adjusted at the factory by means of sheet iron shims, one or more pillow blocks being provided with a fibre shim and insulated bolts and dowel pins. When not assembled, the shims are tied in bundles and marked so that their proper locations on the base can be identified. With the shims in place, the lower half of the magnet frame and the pillow blocks can be bolted in place as located by the dowel pins. It is well to measure the distance between pillow blocks after the base and lower half of frame are in place (in the case of split frame machines) before the rotating parts are placed in the bearings. If the distance between the bearings is shorter than that given by the drawings or dimension sheets the base has been distorted and its center is lower than its end. To remedy this, shim up under the foot of the pillow block until proper alignment results and the correct bearing spacing is obtained.

The oil wells should then be cleaned carefully and filled to the proper level with good quality mineral oil. The lower halves of the bearing lining should be cleaned, placed in position and coated with oil. The rotor should then be lowered into the bearings after cleaning the shaft where it runs in the bearings, removing any roughness and oiling it. The oil rings should be put in and the top halves of the linings placed in position. The oil rings should be tried to see if they revolve freely and the bearing caps put on and bolted down. In cases where the magnet frame is in two halves, the top half of the frame can then be put in place and the brush rigging assembled.

In sets having three or more bearings, the alignment should be checked again after the set has been completely erected. This is best done by backing off the coupling bolts slightly and turning the machine over by hand or with a crane. The coupling halves will separate if the two shafts are out of line, the space between the halves indicating the direction in which the alignment must be adjusted. In this connection it must be remembered that the shoulder between the halves of the coupling carries the weight, the bolts do the driving and must not be used to draw the two halves of the coupling together unless the faces are perfectly parallel. Great care must be used in this checking as large shafts may be broken from crystallization after a few weeks operation when out of alignment, although there are no indications of undue vibration or heating of the bearings.

In erecting machines care should be taken to see that both coupling faces are true and at right angles with the center line of their respective shafts before aligning the machine. It is also advisable to check the outside of both halves of the coupling to see that they are concentric with the center of the shaft. Couplings are frequently distorted in installation so that they are not concentric with the shaft and the face is not at right angles with the center line of the shaft.

After erecting a new machine it is advisable to oil slightly all finished iron and steel surfaces to prevent rusting.

BRUSHES AND BRUSH RIGGING ASSEMBLY

To insure the correct assembly of the magnet frame and brush-holder yoke, the drawings of the generator supplied by the manufacturer should be referred to. These drawings or diagrams locate the position of the field openings or leads with respect to the commutator end of the machine. The outline drawing shows the relation of the lugs on the brush-holder yoke for bolting on the brush-holder bracket with respect to the field coils, thus indicating the correct assembly of the yoke in its supporting brackets.

SPACING THE BRUSHES

To obtain first class commutation, the studs supporting the direct-current brushes must be more carefully set than if merely bolted in the yokes and allowed to come where they will. Spacing by counting of segments is not sufficiently accurate in all cases, as mica thickness varies sufficiently to give slightly different spacing to different sections of the commutator. To obtain proper spacing, the studs should be set up with the brush holders in place, and the commutator should be wrapped tightly with a long strip of paper covering its whole circumference and tied in place. The lapping point of this paper should then be marked, the paper should be removed, spread on a flat surface and stepped off with a large pair of dividers or similar tool into exactly equal sections, equal in number to the number of poles. The strip should then be replaced on the commutator and the studs so adjusted that the toes of the brushes on the different studs just touch these marks.

BRUSH HOLDERS

The brush holders should be mounted on the studs according to the instructions furnished with the generator. Parallelism of the studs and commutator segments is usually insured by the factory machining of the insulating collars, but should be checked if these become warped, sprung or swollen. All brush holders should be at the same distance from the commutator, not over one-eighth of an inch at the inboard and outboard ends, and the toes of all brushes on one stud should line with the edge of the one segment. If a stud is out of line in either of these directions, the insulating collars should be filed to correct it.

STAGGERING OF BRUSHES

The brushes should be staggered so that they will not follow each other's tracks on the commutator. Better results are obtained by staggering the brushes on all positive studs with reference to each other, and those on all negative studs with reference to each other. Collector ring brushes on 3-wire machines, should be staggered so as to distribute the wear over the full width of the collector rings, thus preventing the formation of grooves in the rings.

FITTING THE BRUSHES

After the parts are all assembled, the brushes should be fitted as closely as possible to the curvature of the commutator, the final fitting being done with very fine sandpaper. Best results are obtained by pressing the brush down in the box with one hand and drawing the sandpaper under it in the direction of rotation with the other, raising the brush between "cuts" and always holding the sandpaper down against the curvature of the commutator to guard against cutting away the edge of the brush. This method of sanding will minimize the length of time that the machine must be run light before load may be put on. A proper fit cannot be obtained by working a strip of sandpaper back and forth under the brush held in the brush holder by the spring. Never use emery or carborundum as the particles will imbed in the brush and commutator, producing continuous cutting.

BRUSH PRESSURE

The proper adjustment of spring pressure on the generator brushes depends upon the material and size of the brush. Carbon brushes should be run at a pressure of two pounds per square inch of cross sectional (not contact) area on all sizes up to three-quarters of an inch thick. One and three-quarter pounds per square inch is sufficient on larger sizes. Graphite brushes may be run at pressure as low as one pound per square inch for all sizes. The motor brush pressure should be from one and three-quarters to two pounds per square inch.

SETTING OF BRUSHES OF COMMUTATING-POLE GENERATORS

The brushes of commutating-pole generators are generally set on the mechanical neutral, that is, opposite the mid-point of the main pole arc. It may be necessary in some cases to shift the brushes slightly from the neutral point in order to secure the best commutation, or more stable parallel operation. A tram, with directions for its use in locating the brushes properly with respect to the poles is sent out with some machines. The brush position should be marked on the commutator by means of this tram before the brush-holder brackets are assembled, as the brackets may interfere with the use of the tram. When a tram is not furnished the mechanical neutral may be determined from the factory marks on the armature slots and commutator bars, or by other methods given in the detailed instructions shipped with the machine. The brushes of the nearest stud should be set on the center of the group of commutator bars at the neutral point.

OIL RINGS AND PULLEYS

It should be remembered that in a machine which has solid oil rings, these rings should be placed on the shaft before the pulley in case a machine is so fitted, and the pulley should be placed on the shaft before the armature is slung into place.

If the pulley has a split hub, and if trouble is experienced in slipping it on the shaft, wedges may be driven into the hub, increasing the diameter of the bore slightly so that it will slide into place easily; before driving in the wedges, the clamping bolts should be loosened as otherwise the pulley may be broken. The wedges should then be withdrawn; the bolts clamping the pulley on the shaft should be tightened before the check nuts are set up and lastly, the set screws over the key should be firmly screwed down.

OIL GUARDS

Oil guards to prevent leakage or throwing of oil from the engine bearings on any part of the generator, particularly the commutator, must be provided by the engine builders in cases of engine-driven units. Great care must be exercised in the design of these oil guards on account of the suction caused by modern ventilating methods. The men in charge of erecting the generators should immediately warn the purchaser if the engine bearings throw oil.

PRESSING THE ARMATURE ON THE SHAFT

The following instructions may be used when it is necessary to press the armature on the shaft at the location of the installation.

Under all ordinary circumstances the shaft and spider should be pressed together at the same temperature.

Before attempting to press an armature on a shaft, both the bore and shaft should be carefully calipered to obtain some idea of the fit. If the fit is found to be too tight, the shaft should have any high spots filed off.

The shaft and armature should be a pressing fit only at the spot where they are finally to remain together and the shaft should be turned to a smaller diameter at other places. If this has been overlooked by the engine builder, it should be attended to, if possible, before the work of pressing is undertaken. If it cannot be turned, the shaft should be eased off with a file, except at the places above mentioned, in order to obviate the necessity of pressing the armature over the entire length of the shaft.

All bolts, straps and blocks used on the work should be ready before starting the operation of pressing, which, when once started should be completed as soon as possible. If the armature is allowed to stand over night half pressed on, an abnormal amount of pressure will be required to start it again.

The long rods which are used for drawing the armature on should be placed as nearly parallel with the shaft as possible, in order to keep the armature from twisting. If the keyway runs the whole length of the part over which the armature is to slide, this will not be so important, as a temporary or permanent key can be used to keep the keyways parallel.

The long rods used for drawing on the armature should be from one and one-half to three and one-half inches diameter with a short thread on one end for a nut, and the long thread should be cut up from three to six feet, as the case may require. Blocking from 6 inches square to 10 inches square or any suitable combination of blocking that can be picked up, or pieces 4 inches × 10 inches set on edge with a strap across for the rods might be used instead of boring holes in solid timbers.

If the shaft has had the high spots filed off and is still so large as to render the pressing difficult, the hub may be heated. A variation of .015 inches to .020 inches will cause a considerable difference in the ease of pressing.

Great care should be taken to heat the hub uniformly so that the hole may not be twisted out of round and be larger in one direction and smaller in the other than before heating. Care must be taken not to damage the insulation either by heating or in cooling off with water.

It sometimes happens that the shaft has been stored in a much warmer place than the spider for some time previous to the pressing on of the latter. In this case the temperature may be reduced by packing the shaft in ice for a few hours, thus contracting it to its proper size. This requirement is seldom met in practice however.

If a considerable amount is to be gained, cracked ice mixed with salt is recommended, as the resulting temperature will be at least 15 or 20 degrees lower. It may be noted that the coefficient of expansion for untempered steel is practically 0.000006 per degree Fahrenheit; that is, each inch of steel will expand this amount for each degree Fahrenheit that it is heated.

If the shaft and armature are to be put together while one is hot and the other cold it will be very important to have everything ready before starting, as the work must be finished quickly. The shaft should be very carefully marked in advance for the position of the armature so that no time will be wasted.

Should an excessive variation be found between the armature bore and shaft diameter, the shaft should be checked with the gauges furnished by the manufacturer to the engine builder, and if the error is in the shaft the engine builder should correct it before proceeding with the assembly.

It is customary to make the following allowances for pressing fits:

Shafts up to 5 inches in diameter	0.001 inch
Between 5 inches and 12 inches	0.002 inch
Between 12 inches and 18 inches	0.003 inch
Above 18 inches	0.004 inch

The amount of pressure required to force shafts of different diameters depends so much on conditions and comparative temperatures of the shaft and spider, that it is quite impossible to set any definite pressure required for assembling.

It may be expected that for shafts up to 5 inches in diameter a pressure of between 10 and 35 tons is necessary. Up to 12 inches pressure between 25 and 90 tons. Up to 18 inches between 50 and 140 tons. Above 18 inches between 80 and 200, or even 300 tons would be required.

A difference in temperature of a very few degrees may change the above maximum and minimum amounts very materially in any particular case, but with all conditions favorable the above may be considered good pressing fits.

CHAPTER IV

THE STARTING AND OPERATION OF DIRECT-CURRENT MOTORS.

General Inspection — Starting Up — Operation — Stopping—Reversing—Operation as a Generator—Care and Maintenance—Commutator Grinding and Turning — Treatment of Commutator and Brushes — Bearing Lubrication

The Starting and Operation of Direct-current Motors.—The Manufacturers of electrical machinery furnish as far as possible, apparatus which will perform the service required without delay or trouble, making tests before shipments to insure against failure of any part after delivery to the purchaser's plant. However, it is not possible to locate all defects and weaknesses during the factory tests, and in many cases shipment has to be made without these tests due to urgent need of the machines for emergency conditions. For these reasons and very often on account of damages done in shipments, the apparatus when first installed and started immediately develops slight troubles. It is important that the cause of such troubles, whether due to improper adjustments at the factory or to damage received in transit, be removed at once as a delay in correcting even a trifling defect may result in a serious failure of the units or the parts of units, which would shut down the entire plant and require the services of trained experts to make repairs. In case of trouble upon starting, the unit should be shut down at once and a thorough examination made to locate the cause of the faulty operation but if no apparent cause for the action is found, no experiments upon the units should be permitted by inexperienced hands.

GENERAL INSPECTION

When the assembly work has been completed no attempt should be made to start the motor until a final inspection of the entire unit is completed. Electrical as well as mechanical defects should be remedied before attempting to start up and a list of special points is given below which should be carefully considered to insure against any troubles or defects which may result from oversight.

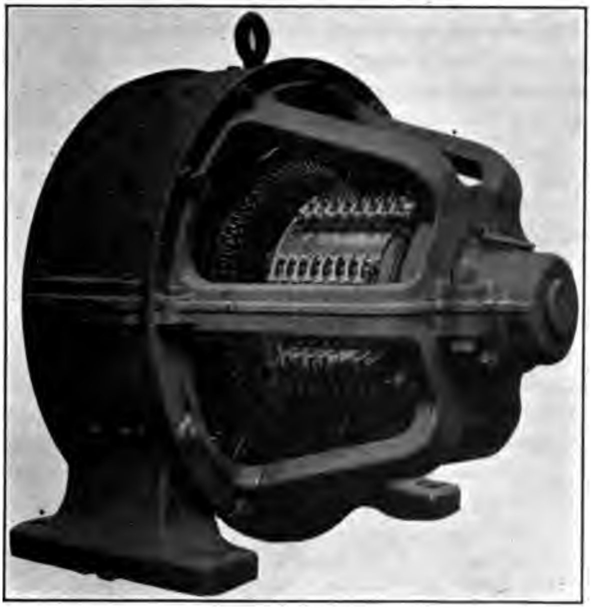


FIG. 37.—Compound wound motor.

A compound wound motor of the end shield type manufactured by the Westinghouse Electrical Co.

1. The voltage on the name plate of the motor should be checked with the voltage of the circuit from which the motor is to take power.
2. The electrical connections should be compared with the drawings furnished with the motor.
3. Broken or damaged parts must be replaced or repaired. See Page 247 of Chapter VIII on "Tests and Repairs."

4. Loose bolts, nuts, washers or tools must be removed from all moving parts and so placed as to prevent falling into the motor while running.

5. All bolts holding poles to the frames and those holding the brush-holder brackets to the yoke should be tight to prevent movement of the poles or brush holders when power is applied. The holding down and foundation bolts should all be in place and tight. The brush holders should be tight on the bracket or studs.

6. Loose connections at the brushes or at the points of contact with the brackets or studs will cause commutation trouble and these contacts must be perfect, clean and tight.

7. The main field air gaps must be uniform as well as the gaps under the commutating poles, but it should be noted that the two gaps may not be of the same size. The air gap should be measured with the armature stationary, after which the armature should be rotated and the gap measured in several positions to avoid error due to the armature being out of round. The air gaps should be measured from iron to iron whenever possible.

8. The commutator segments should be examined carefully to guard against short circuits between bars due to bridges of copper or damage caused by a blow or in rough handling. Where the mica between the segments is grooved or cut below the surface of the copper segments the grooves should be clear of all dirt or metal particles.

9. The armature should turn free in its bearings and it is advisable to turn the revolving part by hand before starting when the size of the unit permits.

10. The commutator leads and clips, also all of the armature clips both front and back, should be straightened out if bent together in assembling or handling.

11. Damaged insulation at the ends of the commutator, on the armature binding bands, field coils, and pole face connections should be given a treatment of good insulating varnish to close all openings through which dirt or oil might enter.

12. The clearances between live parts where full voltage exists to the ground or where full potential exists between connections, must be ample to prevent arcing or grounding. Voltages up to 125 should be given a clearance not less than three-eighth inch and above 125 volts at least one-half inch to three-fourth inch should be allowed. Where the connection strips are not stiff enough to

be self-supporting, spacers should be supplied to prevent contact when the power is applied.

13. The pole tips should be straight and all laminations not in line should be forced back into place.

14. The center line of the armature core should be the same as the center line of the pole pieces.

15. The bearings should be filled with a light grade of good mineral oil to the proper level as shown by the sight gauges. The oil rings should turn free on the shaft and in the oil well.

16. The bearings must not leak oil particularly around the commutator end of the unit.

17. The connection strip must not rub on the binding bands of the armature. The brush holders must be clear of the commutator surface by at least one-sixteenth inch.

18. The brushes must be free to move in the holders and the springs set to give an average pressure of one and three-fourth pounds per square inch of contact surface. The brushes should be carefully fitted to the commutator surface.

19. The brushes should be equally spaced around the commutator and the brackets or studs carrying the holders must be set so that all holders are at an equal distance from the commutator surface. The center line of all of the brushes must be parallel to the commutator segments or side mica.

20. The brushes should be staggered in such a way as to cover the entire surface of the commutator in order to prevent grooving or scoring. The brush holders should be staggered in pairs of studs. The holders should be placed in position as directed by the instructions furnished with the machine.

21. The pulley or coupling should be tight to prevent slipping.

22. All dirt, grit, carbon dust, lint, etc., must be blown out of the machine by compressed air or by the use of a small hand bellows. The best results from blowing out are obtained by the blowing from the back end of the machine toward the commutator.

23. The copper connections between the brushes and the brackets or bus bars must not be allowed to touch rotating parts of the armature or parts not insulated from the ground.

STARTING UP

Shunt Motors.—After the general inspection has been made the machine may be started. Very small motors such as fan motors are thrown directly on the line, but larger sizes are fitted with a starting resistance connected as shown in Figure 38. The wiring as shown is so arranged that the shunt field (*B*) is excited as soon as the main line switch (*D*) is closed. The fields, with or without separate switches in the line, should be excited before the armature circuit is closed through the starting resistance. Care should be exercised to connect the shunt field terminals (*A*) and (*C*) direct to full voltage supply. For example, if (*C*) were connected at (*G*) instead of as shown, the starting resistances (*R*) would be in series with the field and the full voltage could not be applied to the shunt field until the armature resistance was completely cut out. In this case the fields would be under-excited upon starting and the starting torque which depends directly upon strength of the field and armature current, would be reduced materially.

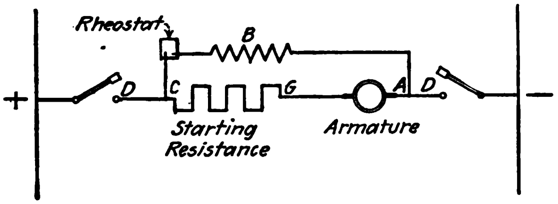


FIG. 38.—Sketch showing the connections for a shunt wound motor.

If the motor refuses to start when the full current shown by the ammeter is flowing in the armature, the poles should be tried for magnetism. In case the poles fail to attract pieces of steel or iron held in the hand to a noticeable degree, the connections to the fields should be examined and a circuit established, to produce magnetism before cutting out more resistance and thereby increasing the armature current to a point where damage might result from heating. If the field is found to be strong and the armature current is flowing, failure to start may be due to friction of the belt, bearings, gears or shafting. Shaking the belt or giving help to start the rotor by hand frequently breaks up such conditions and often helps motors of smaller sizes for the first time, after which no further trouble is experienced.

In Chapter VII on "Troubles and Remedies" other causes of failure to start will be discussed.

OPERATION

Shunt Motors.—After the motor has come up to full speed and all of the armature resistance has been cut out, an inspection should be made at once to make sure that the oil rings are turning and that the brushes are riding properly on the commutator without sticking in holders, chattering, sparking or making excessive noise. The commutator should run true. The mechanical balance of the machine should also be noted by placing the hand on the bearings carrying the revolving parts, to note if vibration is present. The armature should float freely in the bearings without tending to hold to one end or the other. All restrictions to ventilation should be cleared away so that the machine may have a proper circulation of air. When first started the bearings should be watched closely for heating until a constant temperature has been reached.

Commutating pole motors do not require shifting of the brushes as the load rises from no load to full load but it may be necessary with machines not so equipped to shift the brushes to prevent sparking as the load comes on. Shifting against rotation or "back" is correct for motors when the sparking is due to loading up. It is nearly always possible to find a point for the brush position where the operation at all loads will be satisfactory and it is advisable to set the brushes on this point and allow a little sparking at the two extremes, that is, at zero and full load, as no harm will result unless the motor is overloaded, in which case some shifting of the brushes is necessary.

The speed of shunt motors will rise as the fields become warm or hot and for this reason checks on the speed should not be made until the temperatures have become constant, after which the resistance of the field and excitation current will not change.

Once started, shunt motors require very little attention excepting to see that the brushes are kept free in the holders and that the machine is kept as free as possible from dirt and dust by frequent cleaning and blowing out. The oil in the bearings should be changed at regular intervals depending on the service. Bearings exposed so as to collect grit, concrete dust and such material require a change of oil every two weeks as compared with pump motors or motors operating in locations free from foreign matter where a change of oil every sixty days will suffice. The mica between the commutator segments, if flush with the surface, should be sand papered down when an examination shows this mica to be above the surface of the copper. If grooved or undercut mica is used, it should be kept below surface by slotting when necessary.

The brushes should be changed before they become worn to a point where the metal connections damage the commutator. The springs should be notched up to keep the pressure constant as the brushes wear down.

Oil leaks must not be permitted, particularly about the commutator, as failure of insulation would result in a short time.

STOPPING

Shunt Motors.—First, pull the line switch or throw out the circuit breaker, then open the shunt field circuit.

Never open the field circuit of any motor to shut it down as the machine will run away or race or flash over, doing damage to the brushes, commutator and connections. After shutting down, make sure that the starting resistance, if not automatic, is thrown in position to place all resistance in the line. Never leave the starting box in a running position after shutting down.

REVERSING

Shunt Motors.—To reverse the direction of rotation of a shunt motor, reverse either the shunt field terminal connections or the armature terminals. Do not reverse both as the direction of rotation will then remain the same. In motors equipped with commutating poles, no shifting of the brushes will be necessary upon reversal of rotation but motors without commutating poles require that the brushes be shifted against rotation the same amount as with the previous rotation. Motors equipped with brushes set at an angle with the horizontal greater than 20 degrees, should have their brushes or studs turned when reversed rotation is required. Below this angle no change is necessary. Most motors are equipped with a brush rigging to permit operation in either direction of rotation but in large sizes where the rotation is fixed, holders with a large angle, 20 degrees or more, may be employed, which require changing as mentioned above, when reversed operation is desired.

THE STARTING AND OPERATING OF COMPOUND MOTORS

After a careful inspection, the compound-wound motor may be started, operated and stopped according to the instructions given under shunt-motor operation, with the exception of the reversal of rotation. To change the direction of rotation of a compound motor it is necessary to reverse both the series and shunt fields or to change the connections to the armature. When the motor is fitted with commutating poles no shifting of the brushes is necessary upon reversal and when not so equipped, the precautions to be observed in shifting the brushes will be as noted under shunt-motor operation.

THE STARTING AND OPERATING OF SERIES MOTORS

Series motors are controlled by a resistance placed in the armature and field circuits. The general instructions covering the starting and operating of series motors will be the same as those given under shunt-motor operation and it should be noted that a change in the direction of rotation is obtained by reversing either the field or armature leads but not both at the same time. The starting equipment is the same as that used for the shunt and compound motors, omitting the shunt field connections where the motors are operating on a constant load and at a constant speed, such as in the case of fans or pumps. Where the motor is operating at variable speeds and loads, the starting equipment must have ample current-carrying capacity to operate in the line continuously for the purpose of regulating the speed. Series motors should be connected to a load which cannot be dropped, as racing will follow as a result of the loss of load.

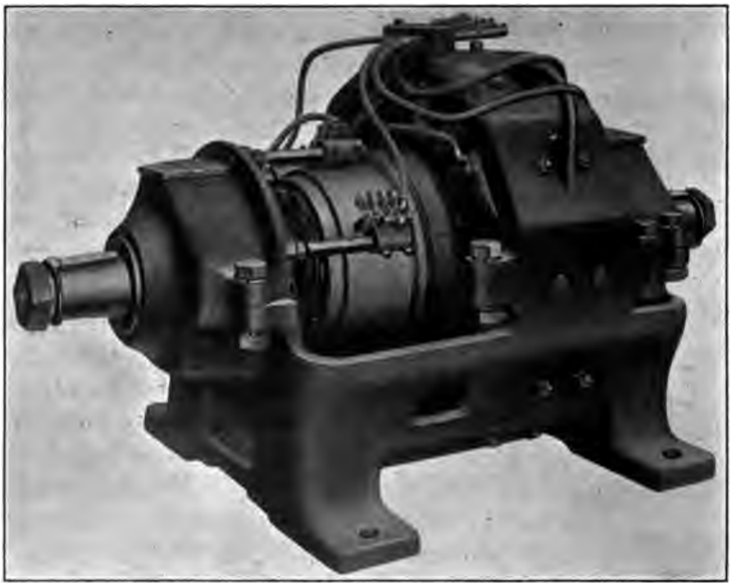


FIG. 39.—Series wound motor.

GENERAL

Direct-current motors of any type may be operated as generators by supplying mechanical energy to the shaft and changing the field connections for voltage generation. Unless the machine has been designed for operation both as a motor and generator however, it will be found that the fields are not of sufficient strength to generate the full rated line voltage without high field temperatures, since the drop or loss of voltage in the generator has to be generated in addition to the terminal voltage. Full-line voltage may be obtained by increasing the speed without danger mechanically and this is quite common practice.

To operate a shunt motor as a generator no change is necessary in the field or armature connections.

To operate a compound-wound motor as a generator it is necessary to reverse the series field only, leaving the armature and shunt field connections in their original positions.

CARE AND MAINTENANCE

A systematic inspection of the set should be made at least once a week, keeping the following points in mind.

Cleanliness.—See that both the interior and exterior of the machines are kept free from metal dust, dirt of any description, oil or water. Take particular pains to prevent dirt or metal dust from collecting inside the end windings of the armature, both in the coupling and the commutator ends. Every precaution is taken in the construction of machines to avoid trouble from this source, but an excessive accumulation of dirt may eventually ground the armature and burn it out. Compressed air is the most effective means of cleansing the interior parts, but a small bellows can be used if compressed air is not available. Wipe the brush holder studs and leads carefully to remove all traces of metal dust worn from the commutator and clean the motor brushes and brush holders.

Blow the machine out at least once a day; if it cannot be taken out of service and shut down, blow it out while running. After blowing out a machine standing stationary, start it up and blow it out again while running on half voltage.

Oil.—See that the oil wells are filled with a good quality of clean mineral oil nearly to the top of the overflow hole of the oil filler, or half-way up the glass gauge, if one is provided. Use heavy oil on large machines. After the first week, the oil should, under average conditions be drained out about every sixty days and replaced with fresh, clean oil. In replacing the drainage plug, it should be dipped in a mixture of red lead and shellac and securely tightened to prevent leakage. When a new machine, or an old machine that has been changed or repaired, is initially started, the oil rings should be watched carefully to see that they revolve freely and carry a sufficient amount of oil to the shaft. Thereafter, the rings need practically no attention as long as a proper supply of oil is maintained in the oil well.

Brushes.—See that the brushes move freely in the holders and make contact properly with the commutator. See that the brushes are properly staggered, so as not to wear grooves in the segments. Try the pressure and keep it up to the proper value as the brushes wear.

Commutator.—See that the commutator maintains a polished surface. Blackening of all the bars indicates poor adjustment of the commutating field, or incorrect brush position. Blackening of groups of bars at regular intervals may be due to the same cause or to poor contacts. Blackening at irregular intervals indicates a rough or eccentric commutator. Ordinarily the commutator will require only an occasional wiping with a piece of dry canvas, or other non-linting material, but if blackening appears and grows worse, the cause must be determined upon and remedied. Use no lubricant on the commutator. Noisy brushes are due to a rough commutator, or to too much clearance between the commutator and brush holders. The use of any lubricant will only cause sparking and aggravate the trouble. The above causes of faulty commutation are discussed in detail in Chapter VII.

COLLECTOR RINGS (THREE-WIRE GENERATORS)

See that the collector rings maintain a smooth, highly polished surface. Ordinarily, the rings will require no attention, provided the brushes are in good condition, but in case the rings cut, or score, a slight amount of oil (not grease) applied at intervals, together with an increase in the brush pressure, will help to restore the desired smooth surface.

Remove any sharp edges that may appear on the rings due to wear.

Bolts.—Go over the bolts and nuts occasionally and tighten them—particularly those in the generator brush rigging.

Speed-limit Devices.—The speed-limit devices should be tested at regular periods. They are designed to operate at 15 per cent. above normal speed. Those furnished on motor generator sets should be tested by cutting off the machine from the alternating-current supply, running it from the direct-current bus bar and gradually weakening the field until the speed rises to a point at which the switch should operate, as noted by a tachometer held against the end of the shaft. If the speed limit device does not operate below 20 per cent. above normal, the machine should be shut down and the defect corrected.

Commutator Grinding or Turning.—In many cases where a commutator is rough but is concentric, it is possible to stone it smooth with sandstone instead of turning. Whenever possible this is to be preferred, for a commutator can usually be smoothed by the removal of a few thousandths in this way, whereas if it were turned, a man would probably cut away one-sixteenth of an inch and possibly more before completing the work.

Before stoning, all traces of oil or grease must be removed from the commutator or the stone will glaze over with copper and will not cut. A piece of grindstone or medium grade scythe-stone will answer the purpose; the stone should be worked from end to end of the commutator and the surface ground down evenly. While stoning, the brushes should be lifted from the commutator as the grit will cut them rapidly.

After stoning, the commutator should be smoothed with fine quartz (not garnet) sandpaper and then polished by using the back of the paper. Before stoning or turning the commutator, the clamping bolts should be tested for tightness while the machine is warm. Extreme caution should be used in tightening the bolts; in many commutators the bolts are strong enough to distort the clamping ring and distortion of the ring will cause serious trouble in the commutator. All commutators are carefully tightened before leaving the factory and should not be tightened afterward unless there is direct evidence of looseness.

When the commutator is too rough or eccentric to be stoned down successfully by hand, the stone may be held by a tool post on a pair of ways, but better results will be obtained by the use of a revolving wheel grinder, Figure 40, or it may even be advisable to turn the commutator before grinding.

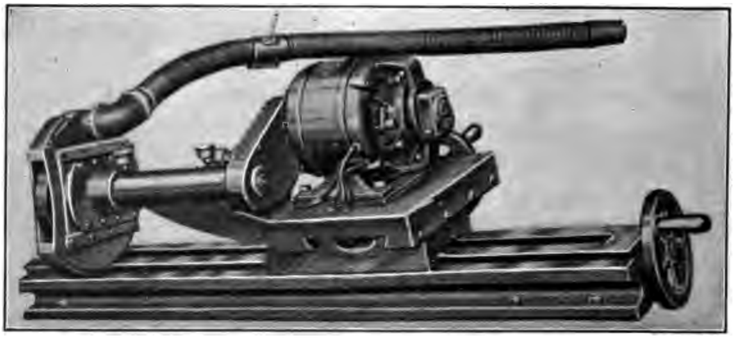


FIG. 40.—Commutator grinding machine.

Before grinding a commutator, a suitable head should be made to prevent chips or dust from working into the armature. This head is best applied by taking a strip of cotton several inches wider than the length of the end connections and long enough to encircle the commutator, wrapping it around the commutator and binding the inside edge with cord as closely as possible to the end connections, the cloth should then be turned up over the end connections and bound with cord to the outside of the armature.

The inside of the machine, field coils, etc., should be carefully covered with oilcloth or some such protection.

Two wheels are shipped with the grinding tool, one a roughing wheel and the other a finish wheel. Generally it is necessary to use the finish wheel only.

The machine should be run at a normal speed, preferably by a pulley and separate driving motor. The grinding wheel should be rotated against the commutator at approximately 1800 r.p.m.

Care should be taken to start the wheel without a jerk, for fear of cracking the inside edge where the stone is attached to the iron disk. The wheel should be started slowly and changed in speed slowly. In feeding the wheel toward the commutator for a cut, be careful to have the wheel barely dust the commutator so as to touch only the high spots. With this cut, the wheel should be carried through, and without changing the feed, the wheel should be again carried across the commutator. The secret of a good job rests in taking the lightest possible cut, thus preventing vibration of tool and wheel.

After the commutator is as true as it is possible to grind it, it is necessary to polish and smooth with the finest grade of sandpaper. When using the sandpaper, a very little pressure should be applied and the paper should be kept moving up and down the surface of the commutator so as to prevent it from developing flats. A little oil applied with the sandpaper will help to give a polished surface. Sandpapering of high-speed commutators should be restricted as much as possible, and should always be done with very light pressure against the commutator.

After finishing, the whole of the machine should be cleaned as carefully as possible, each slot between the commutator segments should be gone through with a small piece of hack-saw or some sharp instrument to remove any grit, copper dust, etc. If the mica appears to be flush with the bars, it should be grooved below the surface at least one-thirty-second inch, using a grooving machine, a hack-saw blade or a curved 3-cornered or riffle file.

As already stated, in order to obtain a finished job, the wheel should be advanced toward the commutator slowly, taking a very light cut and repeating as many times as is necessary to eliminate the eccentricity of the commutator. Unless the commutator of a high-speed machine is true, successful commutation is hardly possible.

Before turning a commutator, a suitable head as previously described should be made to prevent chips or dust from working into the armature. The turning post should be set so that the ways are absolutely parallel with the commutator, and securely fastened and braced. The best tool to use is a side cutting tool with the point ground to about one-sixteenth inch radius. The cutting side and point should be given considerably more rake, as shown in Figure 41, than is customary for use in working steel or iron.

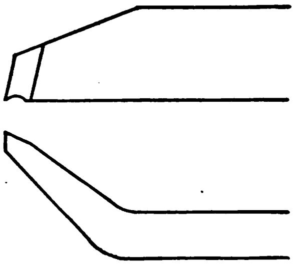


Fig. 41.—Showing point of commutator turning tool.

The commutator surface should be driven at about 300 feet per minute, about as fast as a tool will cut without burning. Care should be taken to see that the tool is sharp enough to make a clean smooth cut without dragging copper over the slots. The ends of the commutator bars should be rounded off with a file while the commutator is in the lathe to at least one-sixteenth inch radius. This is important, for if the commutator is left with sharp corners at the ends of the bars, the mica is easily broken out and short circuits may be established by oil and dust at these points. The commutator should finally be examined carefully to see that there are no small particles of copper bridging the mica between adjacent bars.

It is not out of place at this time to call attention to the fact that commutators must be kept absolutely free from oil or grease, for any oil absorbed by the mica will cause it to crumble gradually and may eventually cause short circuits between bars or ground to the core.

When the machine is again on the line the commutator should receive very close attention at first to see that a good polish is established promptly on the surface. All traces of blackening should be wiped off frequently, and the machine should not be operated for any length of time with poor commutation.

TREATMENT OF COMMUTATOR AND BRUSHES

Generators are frequently shipped with the commutators freshly turned. This and the initial condition of the brush faces do not constitute a fit condition for carrying loads, and heavy loads must not be put upon a generator when first put in service. This point must be insisted upon, for if the machine is misused in this respect, its commutator may reach such a condition as to require turning, and a great deal of trouble may be experienced before proper condition is obtained. If, on the other hand, the following instructions are followed good results are assured.

When the armature is received with the commutator polished from factory testing, the generator may be loaded at once as heavily as the condition of the brush surfaces will permit with good commutation, but if the commutator is not polished, the machine should be run for at least twenty-four hours with normal brush pressure, and then an additional twenty-four hours approximately half load, in order to establish a polish on the commutator surface. The desired surface will show a very high polish by reflected light and will vary in color from a light straw to a dark brown, or even a blue gray, the actual color being of no consequence as long as the bars are polished uniformly from edge to edge.

No lubricant should be used on the commutator either during the polishing period or subsequently. Both the carbon and the graphite brushes now furnished on direct-current generators are self-lubricating, and their characteristics are seriously impaired by the use of any external lubrication. Self-lubricating carbon brushes may in some instances leave a black deposit on the commutator when first put into service. This deposit should be wiped off as rapidly as it appears by means of a piece of dry canvas or other hard, non-linting material which should be wound around a block and held against the commutator with sufficient pressure to remove the blackening.

BEARING LUBRICATION

When oil-ring lubrication is used, the lubricating oil must not be allowed to get so low in the oil well that the ring does not dip into it. If this instruction is observed, satisfactory lubrication will be obtained for all ordinary bearing pressures and up to 100 pounds per square inch with a rubbing speed not exceeding 1500 feet per minute. For higher bearing pressures, or higher speeds, some form of forced lubrication is used. The oil is forced into the bearing either on the bottom, or the lower quarter and enters the bearing at a point such that the revolving shaft draws the oil under the shaft. Oil from forced lubricated bearings is usually returned to an external cooling tank, where its temperature is reduced before being again pumped into the bearing. Oil rings and forced lubrication are occasionally used on the same bearings, so that if the oil pressure fails the rings supply enough oil to prevent danger, until the oil pressure can be restored.

FIG. 42.—Cross section of bearing in place.

A properly designed bearing may run hot from the following causes: oil rings sticking, scarcity or poor quality of lubricating oil; excessive local pressure in the bearing; insufficient relief on the sides of the bearings; improper alignment and excessive belt pull.

The remedy for the greater part of these troubles is obvious. In the case of excessive local pressure in the bearing, or insufficient relief on the side of the bearing, the remedy is to remove the high spots on the babbitt or bearing metal with a scraper and increase the side clearance.

The following formula can be used as a rough guide to estimate the size necessary for a given bearing. If P equals the pressure per square inch of the projected area of the journal and V equals the peripheral velocity of the journal in ft. per min., then PV equals a constant for oil bearings. Ordinary bearings with a constant PV equals 66,000 can be operated successfully where the peripheral speed of the shaft does not exceed 1200 ft. per min.

Before starting a machine all bearings must be filled with the proper amount of oil. Bearings with the end of the bearing shell visible, should be filled with oil until it touches the lower part of the shell at the end of the bearing housing. Where the end of the bearing shell cannot be seen, the bearing should be filled to within three-eighths inch of the top of the visible portion of the oil gauge glass; in the case of sight gauges to within one-eighth inch of the top of the gauge.

Bearings should be inspected to see they have not been carelessly filled; viz., that oil has not been spilled on the bearing housing, or bearing shell, or upon other parts associated with the bearing, otherwise, a false impression may be obtained as to oil leakage or throwing when under test. To give the bearing a critical test for oil leaking or throwing, the dividing line between cap and bearing pedestal and between bearing brackets, should be painted with white chalk. The end of the commutator or field spider adjacent to the bearing should also be given a white coating, so that it is possible to detect, after a comparatively short run, the slightest leakage or throwing of oil.

No oil should be allowed to leak or be thrown from the bearings upon the rotating parts, or windings. This is especially true with reference to commutating machines where it is important that lubricating oil be kept away from the commutator, brushes and fittings. Should oil leaking or throwing on these parts be detected during operation, the machine should be immediately shut down and the leak stopped by refitting or tightening joints. If the bearings during operation rise in temperature 40 degrees or more, above the room temperature, it should be taken as a defect; since no properly designed bearing should heat above 40 degrees under normal conditions. It will usually be found that a greater temperature rise is due to a faulty bearing, resulting from misalignment, loose babbitt, sticking of oil rings, scored shaft, or pitting of the shaft due to circulating electrical currents through the pillow blocks and the base. Faulty bearing action is described in detail under "Troubles and Their Remedies" in Chapter VII.

CHAPTER V

THE STARTING AND OPERATION OF DIRECT-CURRENT GENERATORS

General Inspection—Starting Up—Operation—Stopping—Parallel Operation of Shunt, Compound and Three-wire Generators—Equalizers—Series Operation—Operation as a Motor

As was stated in the preceding chapter on "The Starting and Operation of Direct-current Motors," it is important that slight defects and imperfections should be remedied as soon as noted to prevent trouble from growing to such an extent as to cause a serious shutdown. With generators this is all the more important, since one motor might be only a small part of the equipment while the generating unit is in many cases the supply of power for many motors as well as lights. No experimenting should be permitted by operators unless experienced in handling electrical machinery.

GENERAL INSPECTION

In the previous chapter, attention was called to the special points to be noted before any attempt is made to start the machine. This inspection should be made in case of a generator but in addition, all switches, circuit breakers and connections to the generator should be opened. All wiring diagrams should be checked with the machine connections. Fill the bearings with a good grade of light mineral oil but do not allow the oil to overflow from the bearings.

Rotate the armature by hand to make sure it turns freely in the bearings and note if oil rings turn.

Starting the Generator.—After the inspection is completed the machine is ready to start. Bring it up to speed slowly with all switches open and all resistance cut in on the field rheostat. Examine the oil rings at once and make sure the oil is circulating in the bearings. The brushes should be examined and made free to move in the holders, without chatter or undue noise. The commutator should run true and the mechanical balance should be such as to produce no appreciable vibration, which may be noted if the hand is placed on the bearings carrying the revolving parts.

Bring the prime mover up to full speed and close the shunt field circuit. Allow the voltage to come up slowly, watching the commutator and the brushes, also the armature for any indications of sparking or trouble due to heating, which might come from dirt between the segments or short circuits in the armature not found during inspection. The generator should be brought up to full voltage by cutting out resistance in the shunt field rheostat. (Failure of the generator to "pick up" or generate is due to causes given in Chapter VII covering "Troubles and Remedies.")

After the generator has operated at full voltage for a short time and no trouble has developed from heating or sparking, the circuit breaker and then the switches to the line may be closed and power furnished to the line for use in service. A shunt-wound generator will require hand regulation to keep the voltage constant if the load is not a steady one. If the generator is compound wound, the voltage regulation will be automatic with steady or variable loads.

The load may exceed the rating of the machine or short-circuits on the line may cause the circuit breaker to open. As a precaution against burning the breaker or against personal danger, open the line switch as soon a the breaker has been opened by the overload, then close the breaker and finally the line switch. This system will allow the breaker to open again immediately in case the trouble on the line has not been cleared.

No attempt is made at this point to cover troubles which may arise after the machine is placed in the service. The reader is referred to the chapter covering "Troubles and Remedies" should trouble arise from heating, sparking, etc.

Stopping the Generator.—Reduce the load by cutting down the voltage and open the circuit breaker and the line switches, also the shunt field switch. Then shut down the prime mover.

PARALLEL OPERATION

Assuming that the power plant is overloaded, requiring the operation of additional machines, and as it is neither convenient nor economical to operate two or more generators as separate parts of the same system, the generators should be arranged to operate in parallel, so that all may supply power to a common bus or line or any single generator may supply all the power needed in case the required amount does not exceed the rating or output of that generator at times when the load on the system may be light. In this way the generators may be operated at the most efficient loads, which is in most cases about the normal rating. A single generator and its engine running at full load and maximum efficiency will be a great deal more economical than two generators and their engines running at one-half load. Some plants in operation have three sizes of machines to care for load conditions at maximum efficiency, for example, a station with a maximum load of 300 kilowatts might have three generators, that is, a 300 kilowatt, a 200 kilowatt and a 100 kilowatt machine. The 100 kilowatt generator would take the load when the call for power was light followed by the 200 kilowatt generator when more load came on and finally to take full power the 300 kilowatt unit could be started and the others shut down, keeping the generator on the line for each part of the service at full load. The 100 kilowatt and 200 kilowatt units might also operate in multiple in case of a breakdown in the large unit which is another reason for breaking up the units into parts in a ratio of 1, 2 and 3.

Generators for parallel operation may be shunt or compound wound depending on the service required. Shunt-wound machines operate satisfactorily where the ampere load and voltage are constant as in electrolytic work or charging batteries. In large central stations where the load is practically constant, shunt-wound generators are also operated in parallel. Where the voltage range exceeds 20 per cent. of the normal, separate excitation of the shunt generator may be used to advantage to insure equal division of the load at the lower values.

Where the load is variable such as is the usual power or light circuits or a combination of lighting and elevator circuits, compound-wound generators are used almost entirely when operated in parallel, to avoid the necessity of hand regulation and special attention on the part of the operators.

Parallel Operation of Shunt-wound Generators.—Figure 43 shows the connections for connecting two shunt-wound generators in parallel. The division of the load depends upon the strength of the shunt field of each unit and either machine may be made to take load or drop load by adjusting the shunt field.

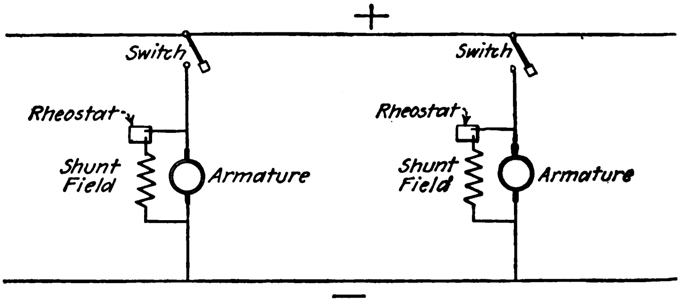


FIG. 43.—Sketch showing the connections for the parallel operation of two shunt wound generators.

Parallel Operation of Compound Generators.—Two or more generators connected in multiple as shown in Figure 44, would operate under steady load without trouble if compounded alike and if the prime movers were properly regulated, but as soon as the load changed, the equal division would be upset, and in a short time there would develop a condition so unstable as to cause serious trouble due to the shifting of the load from one unit to the other as the voltage would rise and fall with changes of speed of the engine.

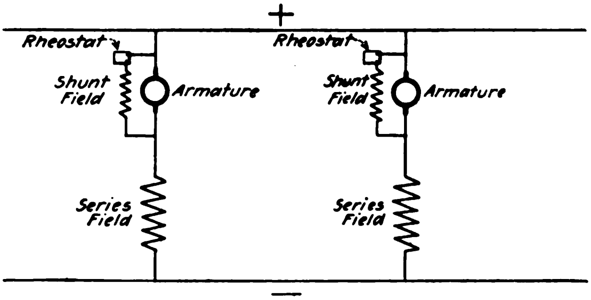


FIG. 44.—Sketch showing the connections for two compound generators operating in parallel without an equalizer.

Figure 45 shows the proper connection for two compound generators operating in parallel, with the addition of an equalizer bus to correct for this unstable condition. The equalizer bus connects the series fields of all generators running in parallel. This connection permits a flow of current from unit to unit through a low-resistance path and good parallel operation is secured provided the following conditions are met.

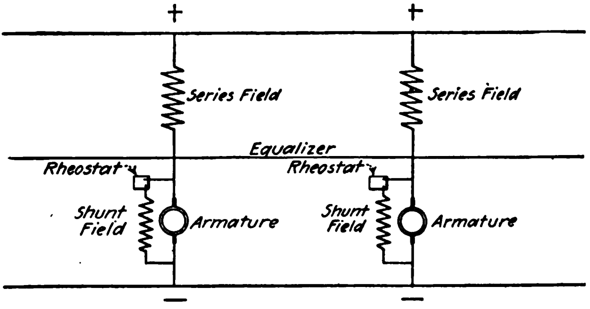


FIG. 45.—Sketch showing the proper connections for the parallel operation of two compound wound generators.

1. The prime movers must have approximately the same speed regulation from no load to full load. On steam engines

this regulation is about 2 per cent. while with gas engines it varies from 2 to 5 per cent.

2. Generators must be compounded from no load to full load at the same voltages. For example, 100 volts no load, 100 volts full load or if over compounded, 100 volts no load, 110 volts full load.

This compounding is done by adjusting the shunt across series field as shown in Figure 46. This shunt may be made of strips of German silver or banks of cast iron grids connected in series or multiple. With German silver shunts, several taps are usually added, making it an easy and quick operation to shift the shunt cable in order to change the adjustment. Where grid shunts are used it is necessary to add or subtract grids for adjustment. With either type of shunt it should be noted that any change made to increase the resistance causes a greater flow of current in the series field since the field resistance is fixed. In general, to increase the voltage by the shunt adjustment with German silver, connect to the taps which connect the greatest length of strips in circuit. In cases where the taps do not give the desired results one or more strips may be cut out to increase the resistance. To decrease the resistance and lower the compounding effect of the field, use taps which shorten length of the resistance. With grid

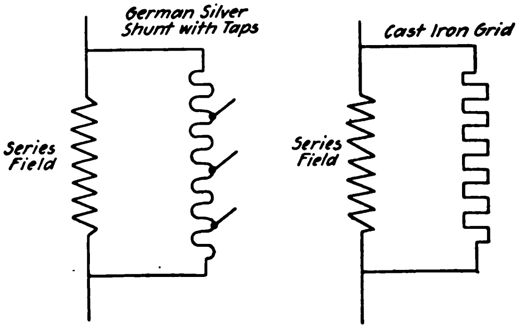


Fig. 46.—Sketches showing a series field with two types of shunts for adjustments.

shunts, adding grids in multiple decreases the compounding and reduces the voltage while removing grids has just the opposite effect. The shunts should not be adjusted while the load is on the machines, particularly if they are running in multiple with other units, as the opening of the shunt circuit may cause a sudden rise of voltage which may burn out lamps if running as a single unit or cause the entire load to come on one machine if running in multiple.

3. It has been shown above that the speed must be approximately constant and the units must be compounded by shunts across the series fields to give practically the same voltage regulation to insure satisfactory parallel operation. It is also necessary that the resistances of the circuits from the point of equalizer connections through the series field and the connecting cables to the common bus should be proportioned to insure a proper division of the current in the series fields of the units in order to operate satisfactorily in multiple. Two machines of the same size and located the same distance from the common bus, connected by the same cables, would operate in multiple without trouble assuming that conditions (1) and (2) have been met. On the other hand, with one unit close to the bus and the second a great distance away, it would be necessary to place larger cables in the line of the second unit, in order to reduce the resistance. This can also be accom-

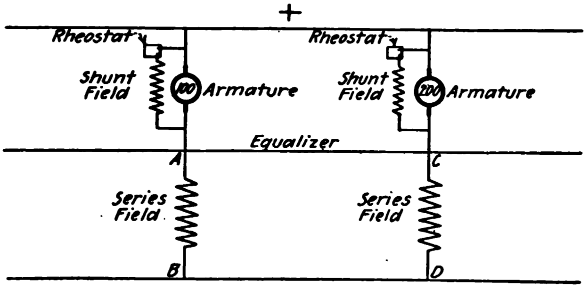


FIG. 47.—Sketch showing the connections for operating a 100 kilowatt and a 200 kilowatt generator in parallel.

plished by adding a line resistance in the short leads of the first unit thereby increasing its resistance.

In units of different sizes or machines of different types or designs where there is an appreciable difference in the resistances of the series fields, special adjustments to equalize the resistances of the circuits are necessary to secure a satisfactory division of the load. For example, if a 100-kilowatt unit is in multiple with a 200-kilowatt unit as shown in Figure 47, and both are located at the same distances from a common bus, there must be twice the resistance in the circuit from *A* to *B* as from *C* to *D*. This is usually taken care of by the size of the cables but the use of the resistance is necessary where an up-to-date type of unit, equipped with commutating poles or compensating windings, or both, is placed in multiple with an old unit.

Parallel Operation of Commutating-pole Generators.—The addition of commutating poles to a generator changes its characteristics to quite a large extent besides improving commutation. Due to the neutralization of the demagnetizing armature reaction, the voltage of shunt-wound generators with commutating poles does not droop as rapidly as that of non-commutating pole generators. If paralleled with one of the latter generators, the commutating pole machine would tend to take more than its share of the load. Due to this smaller drop, a compound-wound commutating-pole generator requires less series field for a given compounding; in some cases one turn around every other pole is more than enough. Such a compound generator would probably require a series resistance to make it share the load proportionately with a non-commutating-pole generator having more turns of series field.

Brushes set back of neutral or an over strong commutating field, will often give a shunt generator a rising instead of a drooping voltage curve. The commutating field then tends to have a compounding effect, due to the commutating field flux.

Referring to Figure 48, if the brushes are set on neutral—on the commutator bars connected to the armature conductors directly under the middle of the commutating poles—the total flux being cut by the armature conductors between brushes is unchanged by the commutating poles. One-half the flux of any south commutating pole is counter-balanced by one-half the flux of the next north commutating pole, leaving the total flux between brushes that of the main field alone. Shifting the brushes forward causes the commutating-pole flux between brushes to subtract from the main-field flux while shifting backward adds to the total flux.

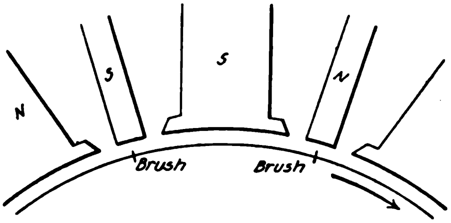


Fig. 48.

The brushes may easily be shifted far enough so that the flux will increase enough as the load increases to cause a rising voltage characteristic of the generator. Too strong an interpole requires shifting of the brushes from the mechanical neutral point to get successful commutation, followed by the results mentioned before for brush position off neutral. The rising characteristic as pointed out in the beginning is fatal to stable paralleling. The remedy obviously is correct setting of the brushes on neutral and adjustment of the commutating-pole shunt.

The resistance is inserted in the line of the new generator to equalize the drop as mentioned above since the new type of generator has a relatively light series-field of few turns as compared with the old unit.

The above discussion may be summed up as follows: The resistances, *AB* and *CD* must be inversely proportional to the full-load amperes of the generator and the resistances may be proportioned in two ways: by the size of the cables or by the line resistances.

EQUALIZERS

When an equalizer is not employed unstable parallel operation must be expected, that is, the load will shift from one machine to an other with every change in speed or in load. The unbalancing under such conditions frequently causes the voltage of one unit to rise to a point due to over-compounding, at which the second unit will take power from the first and run as a motor instead of as a generator. Where the generators are direct connected or belted to engines, this motoring must be guarded against since the series field of the machine operating as a motor will buck the shunt field, which will cause the speed to rise to a point where the engines may be damaged or wrecked.

An equalizer bus connected as shown in Figure 45, prevents such unstable action by allowing current to flow through a low-resistance circuit from the high-voltage generator through the series field of the low-voltage generator and in this way causes the voltage of the low-voltage generator to rise to a point where the generator will again take its share of the load.

The resistance of equalizer busses or cables should be very low and no line resistance should be put in this circuit for equalizing the load. Equalizer leads are very often permanently connected but where a switch is used, the switch should be the first one closed where the generator is to be put in multiple with a unit already in operation. This equalizer switch should be the last switch opened where the generator is disconnected from the common bus. Do not connect a circuit breaker in the equalizer circuit.

STARTING AND OPERATION IN PARALLEL OF TWO OR MORE GENERATORS

First, assuming that one generator is operating on the system or bus and the load requires additional capacity, the second unit may be started as given in the instructions under starting. When the prime mover is up to speed and ready to take load, close the equalizer switch if the equalizer is not permanently connected. Then close the shunt field switch, adjust the voltage by use of the field rheostat until the voltage of the second unit is equal to that of the first. Close the circuit breaker if one is provided, then the main-line switch and adjust the load between the two generators by means of the field rheostat. As the second generator fields begin to warm up, the load will drop due to a weakening of the field and it will be necessary to adjust the load with the rheostat until the field temperature has become constant.

When starting the second unit, it is important that the generator builds up with the polarity (+ or −) in the right direction so as to connect positive to positive or negative to negative when the line switch is closed. A connection of negative to positive would throw the two units in series and build up a heavy voltage and current in the circuit through the two machines. This may be prevented by connecting the equalizer bus permanently or by closing the equalizer switch first when ready to start. Connecting the shunt field terminals to the common bus instead of to the brushes will also guard against reversed polarity.

Fields of generators operating in multiple should not be opened until the line switches are opened as the opening of the shunt field on any one generator will cause that machine to lose its voltage and the machine will become a motor and run away or the armature will become a short-circuit on the system and the other generators will be damaged by flashing or serious overheating.

To shut down a generator operating in multiple with others, reduce the load by use of the field rheostat then open field and equalizer, lastly shut down the prime mover.

MULTIPLE OPERATION OF THREE-WIRE GENERATORS

Three-wire generators may be operated in multiple with each other by using two equalizers one on each side of the armature, positive and negative, see Figure 49. If 3-wire generators are operated in parallel with 2-wire machines it is necessary to split the series fields of the 2-wire generators to permit the use of two equalizers. One half of the series field is placed on the positive side and the other half on the negative side as shown in Figure 50.

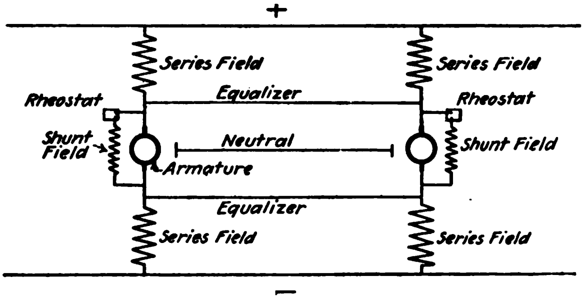


FIG. 49.—Sketch showing the connections for the parallel operation of two three-wire generators.

Three-wire generators may also be operated in multiple with an Edison 3-wire system by placing the series fields of all generators as shown in Figure 51. It should be noted that in this case the series fields are on the positive side of one

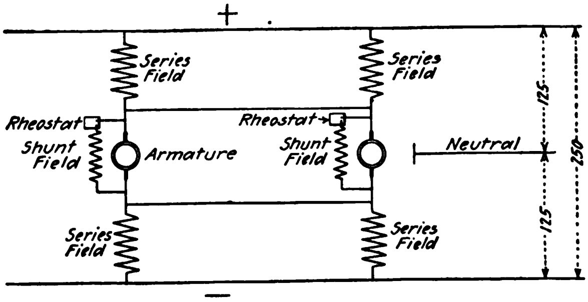


FIG. 50.—Sketch showing the connections for operating a two-wire and a three-wire generator in parallel.

generator and on the negative of the other, not both positive or both negative.

Three-wire generators have two shunts, one on each half of the series field and both should be changed to adjust for compounding for satisfactory operation.

In Edison 3-wire systems both armatures are brought up to speed and the combined voltage of the two in series should be equal to the voltage of the system before the line switches are closed. In other words, treat the two armatures as one machine with respect to the voltage, when connecting them together electrically for parallel operation.

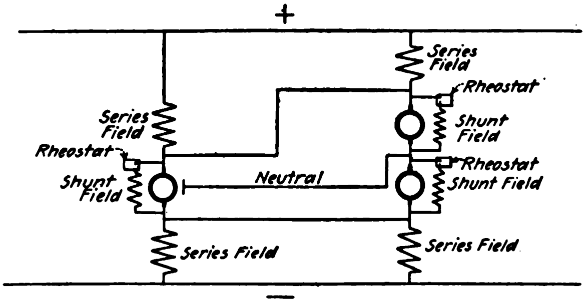


Fig. 51.—Sketch showing the connections for operating a three-wire generator in parallel with two, two-wire generators operating in series.

SERIES OPERATION

Generators whether shunt or compound wound may be operated in series to produce higher voltages. Equalizers *must* be disconnected and the positive side of the first must be connected to the negative side of the second as illustrated in Figure 52.

Attention is called to the danger of putting two or more generators in series unless the insulation is designed to withstand double or more voltage, as the generator on the high or positive side must stand double voltage or more to the ground and the creepage surfaces may not be sufficient to withstand this high voltage. To avoid high voltage to the ground, it is often found desirable to place the ground connection between the two armatures at *A*, with the result that while double voltage is generated, the voltage to the ground remains at the original value. This connection is not possible of course on a circuit which is negatively grounded such as is common in railway practice. Figure 53 shows two generators connected in series with two grounds resulting in a short-circuit on the first unit.

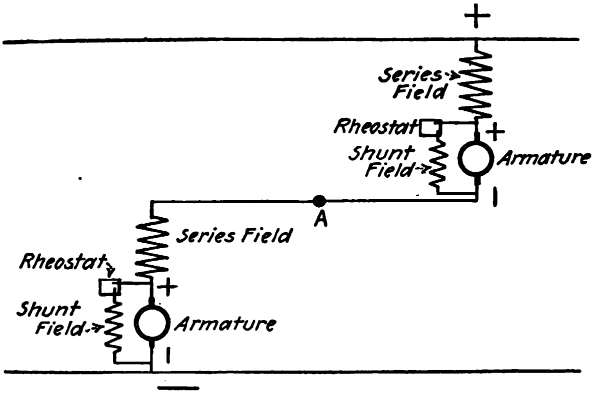


FIG. 52.—Sketch showing two compound wound generators connected in series with a ground between at A.

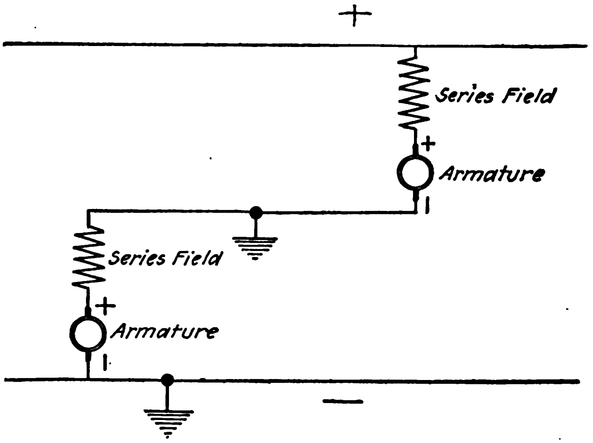


FIG. 53.—Sketch showing two series generators operating in series with two ground connections.

When operating in series, care should be exercised to keep the voltages on each of the two generators approximately one-half of the total voltage to prevent overheating of the shunt fields of one unit which would occur if the entire voltage was generated in one armature.

Both machines should be started and brought up to voltage (each approximately one-half of the required line voltage) after which the circuit breaker and the line switches may be closed. This arrangement should not be confused with two generators in series as in the Edison 3-wire system as mentioned under "Parallel Operation." In the latter case an equalizer bus is used with two generators in series operating in parallel with a 3-wire system as shown in Figure 51. Note that the equalizer connection in this case does not in any way connect the series fields of the two generators running in series as a unit but does connect the series fields of the generators connected in multiple with the two in series, as a unit. An examination of Figure 51 will show clearly the two connections.

OPERATION OF THE GENERATOR AS A MOTOR

Generators, whether shunt or compound wound, may be operated as motors by supplying power to the terminals. A starting resistance is required as described in the chapter covering motors.

Shunt-wound generators require no change in connections to operate them as motors unless the rotation is to be changed, which can be done by reversing the shunt fields. The speed may be varied by use of the shunt field rheostat.

Compound Generators.—Compound generators may be operated as motors by reversing the series field terminals so as to change the direction of current in this field. If this is not done, the motor will have a rising speed curve as the series winding will weaken the field when the load comes on. Where generators are heavily overcompounded, the speed may be so low at full load as to require adjustment of the series field to shunt out more current and reduce the strength of the series winding. This may be done by the use of taps or by changes in grids as described previously for compounding adjustment.

It is well to keep in mind that as the fields are strengthened the speed is lowered. The stronger the series field becomes the greater will be the drop in speed from zero to full load. The series field may be cut out entirely or short-circuited without danger and the generator will then operate as a simple shunt-wound motor.

Generators equipped with commutating poles require no shifting of brushes when changing from generator to motor operation. When the machines are not equipped with commutating poles, the brushes, when operating as a generator should be shifted ahead of the neutral in the direction of rotation. When operating as a motor with the same direction of rotation, it will be necessary to shift the brushes back or opposite to the direction of rotation.

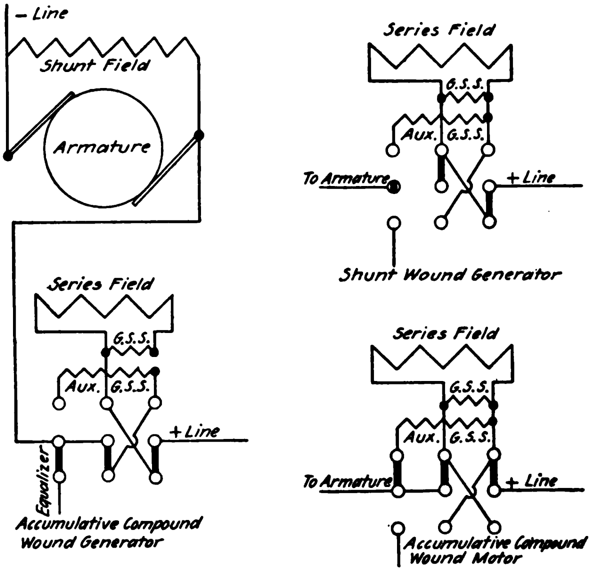


FIG. 54.—Diagram of connections of three single pole, double throw switches for operating a direct current machine either as an accumulative compound wound generator, a shunt generator or an accumulative compound wound motor.

It is not necessary to change the connections to the commutating field since the correct relation is established automatically by the current in the armature being reversed when the power is taken into the machine instead of flowing out from it.

Three-wire generators may be operated as motors by reversing both halves of the series field and opening the connection to the neutral. The compensator may be left in the circuit without danger but the brushes on the collector rings should be raised and the 3-wire features entirely cut out for most efficient operation. (Use the outside wire voltage for driving the motor: not the neutral voltage).

In units of larger sizes which are motor driven, reversing switches as shown in Figure 54 are mounted directly on the frame of the unit. When such a combination is furnished, the adjustment for speed is made by cutting in a second shunt in multiple with the compounding shunt as shown in the figure. This combination of switches also permits shunt operation by short circuiting the series field with a copper strap when one main switch is up and the other down.

STARTING AND OPERATION OF SERIES GENERATORS

Series generators should be subjected to the same general inspection as covered for the other types. They are never operated in multiple but always in series if the conditions require a combination of units. When series generators are used on systems where a constant voltage is supplied, speed-limiting devices set to open the circuit must be supplied if the mechanical power supply is such that it may fail, as a series generator will operate as a motor and if not loaded, will race and wreck itself by overspeed.

Voltage regulation is obtained by a shunt across the series field winding or taps on the winding.

To start, bring the generator up to speed and close the circuit breaker and line switch.

To stop, open the circuit breaker and line switch and then shut down the prime mover.

OPERATION AS A MOTOR

A series generator may be operated as a motor by supplying power to its terminals. The direction of rotation can be reversed by changing either the armature or field terminals but not both. Never connect it to a load which can be lost or dropped on account of the danger of overspeeding given in the above paragraph. A starting box is necessary for motor operation and speed control.

CHAPTER VI

DIRECT-CURRENT SWITCHBOARDS

SHIPMENT AND UNPACKING—INSTALLATION—FOUNDATION—ASSEMBLY—CONNECTIONS—PROTECTION FOR OPERATOR—OPERATION—ILLUMINATION—DIRECTIONS WHEN ORDERING

INSTALLATION AND OPERATION

The conditions of service and the types of switchboards are so varied that it would be impossible to draw up instructions to meet each specific case. The following instructions, however, may be said to cover generally some of the more important points in switchboard installation and operation.

SHIPMENT AND UNPACKING

Switchboards are packed for shipment with great care and it is essential to exercise the same care in unpacking that nothing may be broken or marred, and that no screws, bolts, or other parts may be left in the packing.

After the parts have been unpacked, they should be looked over carefully to see that no foreign material has lodged in the crevices of the apparatus and that parts are in no way injured. Such parts as will not be required immediately should be put away in an orderly manner and in a dry place.

INSTALLATION

Ample space must be provided in front and back of the switchboard so that there will be plenty of room and the switchboard will not be crowded. Allowances should be provided so that further extensions may be made to the switchboard proper and to the wiring.

Electrically operated switches will not necessarily be placed near the controlling board but should usually be placed with regard to convenience of connections and safety from fire and in handling.

Rheostats should be so located that proper ventilation is secured. When this is impossible, special means for ventilating must be provided.

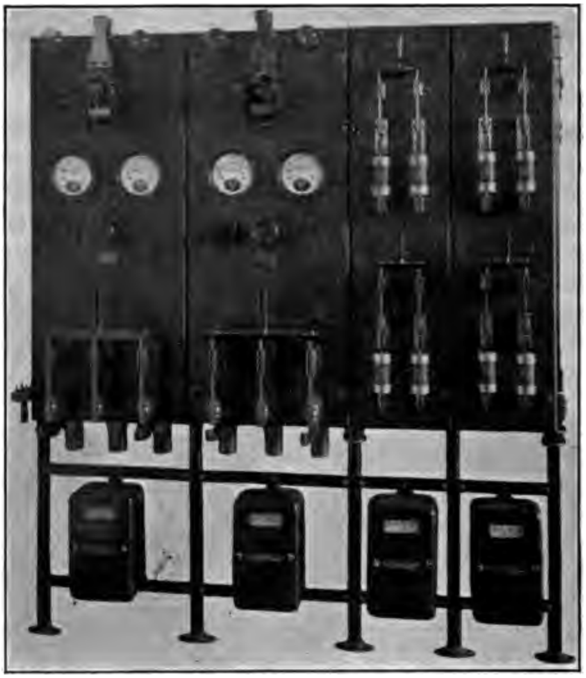


FIG. 55.—A standard direct current switchboard (front view).

Foundation.—The switchboard should stand on a level foundation made of hard wood or channel iron. The sill must be heavy enough so that the panels will not be thrown out of line by settling. Standard six inch channels, or hard wood sills, seven by twelve inches should be used.

Assembly.—The first thing to be done is to set up the supporting framework, preferably for the first three or four panels. The first two panels should then be placed in position and bolted loosely to the supporting irons. The reason for bolting loosely at first is to avoid cracking the marble or slate when lining up the panels, as these materials have no flexibility and are comparatively brittle. With all panel bolts, either paper or fibre washers should be used between the panel and the iron work. The panels should then be carefully leveled and when in correct alignment, the panel bolts should be securely tightened. Proceed similarly with the other panels, always having the supporting framework for one or two panels in place and lined up ahead of the panels which are being placed

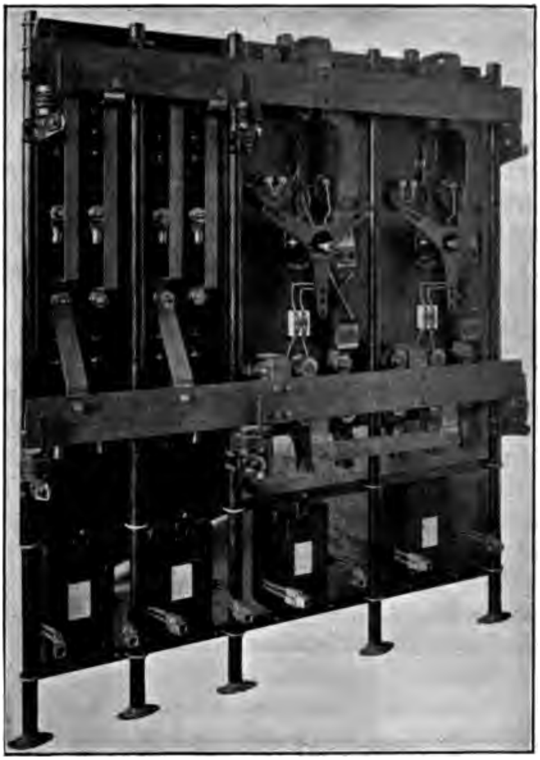


FIG. 56.—A standard direct current switchboard showing connections (rear view).

in position, until all panels are in place. When pipe framework is to be grounded, all joints between pipes should be scraped clean of paint and dirt before assembling. The different devices which have been shipped separately should then be placed on their respective panels.

CONNECTIONS

The connections should be assembled on the back of the panels, consulting the switchboard drawing to see that everything is in its proper place. Carefully read and follow the instructions sent with the different devices. All wiring should be done in a neat and safe manner. Special attention should be given to the joints, whether bolted joints of copper bars or soldered or clamped joints of wires or cables. All parts that are to form joints should be perfectly clean, bright, and free from burrs. Nuts on current-carrying studs should be securely screwed against the connection bars or terminal lugs in order to give as good contact as possible. All bus bars and bare copper conductors should be thoroughly cleaned with sandpaper and oil and given a coat of transparent lacquer to prevent the copper from tarnishing and to preserve a neat and bright appearance. This should be done after all joints are made up.

Spacings and Sizes of Wires.—The following table gives the clearances for live conductors in switchboard construction:

Voltage of circuit	Clearance to ground in inches				Clearance between opposite polarity in inches			
	In air		On surface[1]		In air		On surface[1]	
	Recommended	Minimum	Recommended	Minimum	Recommended	Minimum	Recommended	Minimum
125	¾	½	1¼	¾	¾	½	1	¾
250	1	¾	1½	1	1	¾	1¼	1
600	1½	1	2	1½	1¾	1	2	1½
1200	2	1½	2½	2	2	1½	2½	2
2400	2½	2	...	2½	2½	2	...	2½

[1] For slate up to 1500 volts, marble and soapstone only.

INSULATION

To prevent the weakening of the insulation, avoid as much as possible, sharp turns, corners, and edges. The radius of bend for rubber-covered varnished cambric or lead-covered cable should never be less than six times the outside diameter of the cable. With small braided conductors, the radius of bend may be five times the outside diameter of the cable.

All cable and wire joints should be safely insulated.

When conductors are carried in compartments, or high enough above the station floor to preclude the danger of accidental touch or contact, they may be bare, relying on safe distances and suitable insulators.

The busses are an important part of the installation, carrying the whole energy of the plant in a confined space, thus making it essential to use extreme care, both in selecting the proper materials for construction and in the quality of the workmanship. When building bus compartments, arrangements should be made so that the joints are accessible for inspection and such other work as may be necessary. Connections between switches and busses are practically part of the installation.

Connections to Ground.—Panel supports should ordinarily be grounded except on grounded direct-current systems of 750 volts or less, where only the insulated polarity is brought to the panel. If such direct-current panels are installed in one board, together with alternating-current panels above 600 volts with oil circuit breakers mounted on panel or on panel pipes, all panel supporting pipes should be grounded.

Switchboard devices for operating at 150 volts and above to ground, should have their exposed bare metal parts, which are insulated from the current-carrying parts, permanently grounded unless isolated by elevation or protected by suitable permanent insulating barriers or guards. This rule covers, for example, transformer casings, operating mechanisms for switches, oil circuit breakers, air circuit breakers, rheostats, compensators, etc. Air circuit breakers above 300 volts, the frames of which are not insulated from the current-carrying parts, should always be isolated by elevation.

One common ground bus, not less than No. 4 B. & S., should be run across the back of the switchboard, to which apparatus mounted on the switchboard intended for grounding should be connected. The switchboard pipe framework, except when insulated, should be connected to this ground bus, one connection being made for every three pipe joints in series.

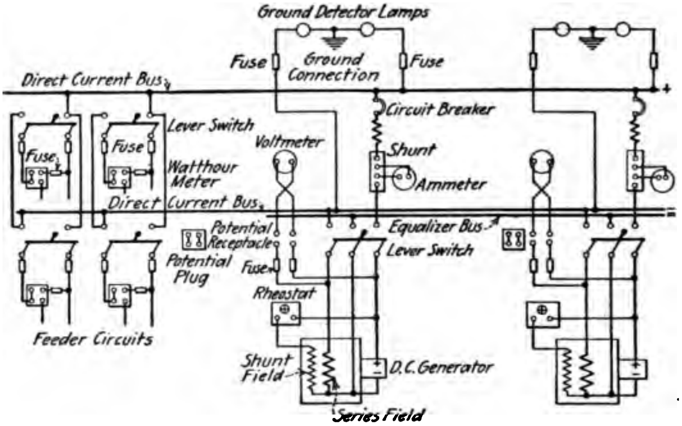


FIG. 57.—A wiring diagram showing the connections on the standard switchboard illustrated in Figs. 55 and 56.

Steel work supporting high potential switching equipment should be carefully grounded at several points so as to prevent the possibility of high voltage occurring between sections of the steel work. No ground connection for this service should be of less than No. 6 B. & S. flexible cable.

PROTECTION FOR OPERATOR

Where live parts having a potential over 300 volts to ground are not otherwise grounded, suitable insulating floors, mats, or platforms providing good footing should be properly placed so that the operator cannot readily touch the live parts unless standing on such floors, mats, or platforms.

Before working on switchboards, and especially on those rated at 1000 volts and above, it is strongly recommended that all live parts be made "dead" and furthermore, that they be connected to ground.

OPERATION

Before putting the switchboard into service, all connections to instruments, meters, relays, etc., should be carefully traced and checked with the drawings. A preliminary trial should then be made to see that instruments, watthour meters, etc., read or record in the proper direction. In fact, before putting a switchboard into actual service, it is advisable to put current through all parts at reduced voltage in order to bring out any weak spots.

When first putting the switchboard into actual service, every detail should be closely watched and anything out of the ordinary should be carefully noted and investigated. The switchboard should be subjected to periodical inspections of all parts. Attention should be given to the joints in cables, busses, connection bars, current-carrying studs, and to temperature rise, insulation, cleanliness, etc.

In making an inspection or repairing work near live parts, special care should be exercised to avoid accidentally short-circuiting or grounding any of the connections. The following instructions cover only in a general way the routine to follow, as it is obvious that details given, for instance, for a direct-current railway power plant would not apply to a high-voltage, alternating-current power plant. The operator, however, is urged to familiarize himself with these details.

1. Before each starting of the plant, be sure that all switches and circuit breakers involved are open and that no other device is in such condition as to cause trouble when throwing voltage on the panels.

2. After everything is adjusted and running, take frequent readings of instruments to see that no device is overloaded to a dangerous point. This applies to conductors as well as to switches and instruments.

3. Make occasional but regular tests of instruments and meters to locate any inaccuracies, at the same time noting any parts which may need adjusting or repairing.

4. Regularly inspect switches, circuit breakers, and relays to see that contacts are in good condition and that there is no sticking.

5. When circuit breakers or switches with carbon or other secondary contacts are furnished, see that the secondary contacts are in good shape and properly adjusted so that they will take the final break of the arc and prevent arcing at the main contact. See also that there is sufficient contact between the main brush and the contact block.

6. Regularly inspect the back of panels and keep all joints in perfect condition.

7. Regularly clean the switchboard, especially in buildings where there are inflammable particles flying around. In cleaning the back of a board, compressed air applied through a flexible hose and nozzle is the simplest and safest method. If this equipment is not available, a hand bellows may be used. Wiping is not recommended back of the board, although this method of cleaning may be employed on instruments on the front of the board when they are not directly connected to high-tension circuits.

8. To renew the finish of dull black marine slate, black marine slate, and marble panels, soap and cold water should be applied with a soft cloth. A marble panel may also be brightened by rubbing with a cloth dipped in gasolene. Natural black slate may be restored to its original freshness by rubbing with a soft cloth immersed in good engine oil.

9. Knife switches in series with circuit breakers of the carbon break or magnetic blowout type should be closed or opened after the circuit breakers have been closed or opened. When closing the switches, it is well to turn the face away from the switchboard to avoid having the eyes "flashed" in case the circuit breaker should open.

ILLUMINATION

Sufficient illumination should be provided in the station, both for the front and the rear of the switchboard so that the switchboard may be readily operated and instruments and meters conveniently read. It has been found that insufficient illumination, and a badly arranged system of lighting units are responsible for considerable eyestrain and subsequent fatigue and possible accident. The illumination should be so arranged that all instruments and other parts which are to be kept under constant supervision are easily discernible without glare or reflection. Therefore the subject of proper illumination should be given careful consideration.

FIG. 58.—A front view of a special type of direct current switchboard.

It is strongly recommended that a separate emergency source of illumination from storage battery, lanterns, or other suitable source be kept immediately available.

DIRECTIONS WHEN ORDERING

1. Order panels, accessories and extras by catalog number.
2. Give ratings of apparatus and feeders to be controlled

and anticipated overloads on these. For 3-wire systems, state if neutral is to be grounded or not.

3. State if any special order of assembly is desired.

4. Advise fully regarding the space available for installing the switchboard equipment proper and for rheostats when these are driven by sprocket wheel and chain mechanisms. Designate the location desired for sprocket wheel and chain-driven rheostats.

Advice regarding available space should peferably be given in the form of dimensioned prints and sketches, and should include data as to the thickness and construction of the station floor.

5. Designate the size of cables to be used, and if these are to be hemp core or not.

CHAPTER VII

TROUBLES AND THEIR REMEDIES

COMMUTATION—OPERATION OF INTERPOLE DIRECT-CURRENT MACHINES—BRUSH POSITION ON NON-COMMUTATING POLE MACHINES—COMMUTATION TROUBLES AS CAUSED BY THE BRUSHES, COMMUTATOR AND OTHER PARTS—ARMATURE—FIELD—MOTOR—GENERATOR—SHAFT AND BEARING TROUBLES AND NOISE

Peculiar to the operation of every direct-current motor or generator are certain troubles, which although they may scarcely be considered as casualties, often present a baffling problem to the operator. In many cases it is possible to preclude the probability of trouble by systematic inspection and rigid upkeep but with the best of operation and the finest of equipment, there is always the possibility of its occurrence. Where the failure of a generator will mean the shut down of a whole system or the stopping of a motor may mean the interruption or cessation of an important process with costly results, it is really the paramount duty of the operator to preclude all probability of trouble and to possess a complete knowledge of effective remedies in its advent. Theory, while a valuable asset, alone proves a slight solace when the operation of the machine is faulty or it has completely stopped or refused to generate. It is then that experience and a practical knowledge of all of the operating conditions will aid the operator in locating and combating the defective condition.

In the following chapter, no reference to theory will be made unless it is necessary for a clear conception of the trouble, but instead, the symptoms, causes and remedies of direct-current motor and generator troubles will be given. The natural course of events provides practically all operators with a knowledge of and resourcefulness to overcome many of the minor casualties but the most material assistance can be gained from the experiences of designers and manufacturers of electrical machinery, who in the regular course of their duties become acquainted with every possible electrical and mechanical trouble and its remedies. The greatest of all of these troubles in direct-current work is faulty commutation.

COMMUTATION

Commutation may be defined as the process of rectifying the alternating current produced in the armature and collecting and distributing it to the external circuits as direct-current power. All direct-current armatures generate alternating current in their windings due to the cutting of flux alternately from North and South poles, and the commutator presents a medium for the changing of this current to direct current. Commutation is an important and difficult subject, both in theory and in operation and a thorough knowledge of it such as can be obtained from any standard electrical text-book will prove a valuable asset to any operator. Faulty or poor commutation may result from incorrect design but even when direct-current machines are designed with liberal commutating constants, there are a whole host of commutation troubles both electrical and mechanical, which may occur. Brush and commutator troubles present the greatest sources of poor commutation although there are a few other causes, which are described. Of these, the defects in brushes or brush operation represent the most serious menace.

Both in machines not fitted with commutating poles and those of commutating pole design, the position of the brush upon the commutator directly affects commutation, since for the best operation the brushes should always be upon the electrical neutral. With the kind permission of the author, Mr. Justin Lebovici, we are reprinting two articles which appeared in the Electrical World upon "The Operation of Interpole Direct-current Machines," which present a study of the "Location of the Correct Neutral Position for Brushes," and "An Analysis of Best Commutation." Parallel information on non-commutating pole machines directly follows these articles.

OPERATION OF INTERPOLE DIRECT-CURRENT MACHINES

METHODS FOR MAKING ADJUSTMENTS IN USE ON MANUFACTURERS' TEST FLOORS—LOCATION OF CORRECT NEUTRAL POSITION FOR BRUSHES

Different methods for making the necessary adjustments of interpolar machinery to obtain the best results from its operation have been published from time to time. The methods in common use and employed on manufacturers' test floors, however, are not well known to the average operator. Since the interpole machine is usually adjusted for best performance in the factory test and these adjustments may be disturbed during shipment and are, of necessity, disturbed when repairs are undertaken, it is important that proper methods be used in all adjustments

The interpole design was originally used as an antidote for certain commutation troubles, but has later been taken advantage of to obtain a greater output from a given amount of material through removing the limitations imposed on the design by commutation and thus making heating the only obstacle to larger outputs. By improving the methods of ventilation the burden imposed on the interpole grew and new problems came up in interpole machines which were of secondary importance only in non-interpole machines. Thus a slight shift of the brushes from the position of best operation in a non-interpole machine has little effect on the performance. In an interpole machine, on the contrary, a slight shift from the neutral position will produce a surprising cumulative or differential compound effect.

The explanation of this phenomenon can be easily followed by means of the accompanying diagrams. Figure 59 shows the distribution of currents and emfs. in a generator running righthanded or a motor running left-handed. The interpoles induce in a generator the additional emfs. 1, 2, 3, 4, and 1′, 2′, 3′, 4′, having the direction shown. For circuit *ATB* the emfs. 1 and 2 are cancelled by emfs. 1′ and 2′. For the circuit *ALB* the emfs. 3 and 4 are cancelled by emfs. 3′ and 4′. In consequence for the brushes in the neutral position, the voltage between the brushes *AB* is not influenced by the presence of the interpole.

The diagram in Figure 60 represents the same machine as Figure 59, with the brushes shifted from the neutral position forward for the case of a generator, backward for that of a motor.

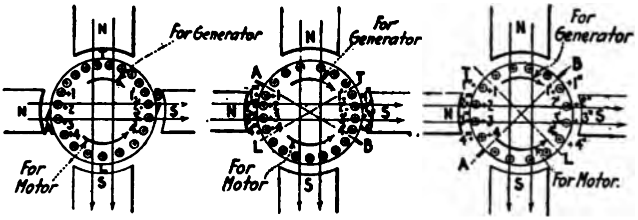


FIG. 59. FIG. 60. FIG. 61.

FIGS. 59 to 61.—Diagrams showing effect of shifting brushes of interpole generator and motor.

The emfs. 1′, 2′, 3′ and 4′ generated by rotation in the interpole flux are opposing the emfs. in circuit *ATB* generated by rotation in the main flux. Similarly emfs. 1, 2, 3 and 4 oppose the emfs. in circuit *ALB*. Consequently the potential between the brushes *AB* is reduced, owing to the presence of the interpole. Or less voltage will be generated if the machine is a generator, owing to differential compound action. If the machine is a motor, 1″, 2″, 3″, 4″—1‴, 2‴, 3‴, 4‴ are the emfs. due to the interpole. They reduce the counter emf. between *AB*, and the motor will move faster than with the brushes at neutral (differential compound action), because the counter emf. is reduced while the applied emf. remains the same. If the interpole flux is strong as compared to the main flux, the variation in speed between light load (interpole flux negligible) and heavy load may be quite marked, and the motor may become unstable or "pump." This pumping may be explained as follows.

Owing to the shift of the brushes from the neutral position against the direction of rotation of the motor the counter-emf. is reduced as explained. Since the applied voltage is the same, the motor must speed up and the current in the armature will rise at the same time. In consequence, the interpole is strengthened and the counter-emf. still further reduced. This action will continue until, owing to the saturation of the interpole the counter-emf., due to the higher speed of the armature, starts to reduce the armature current. If the inertia of the armature and motor load is great, the counter-emf. may rise above the applied potential and the armature will work as a brake. The action is again reversed and a satisfactory operation becomes impossible. If the speed drops too much, the current may rise excessively and short-circuit phenomena may take place.

A similar action takes place if the interpole has too many turns, as will be explained later in this article. Figure 61 is the same as Figure 60, except that the brushes are shifted backward for a generator, forward for a motor. In a generator the emfs. 1, 2, 3, 4 are adding themselves to the emfs. in the circuit *ATB* and the emfs. 1′, 2′, 3′, 4′ are adding up to the emf. generated by rotation in the circuit *ALB*. It follows that the voltage between the brushes *AB* is increased in the generator. The speed is lowered in a motor when the brushes are shifted from the neutral position backward, the emfs. 1″, 2″, 3″, 4″—1‴, 2‴, 3‴, 4‴ increasing the counter-emf. between *AB* so that the motor has to run slower for the same load current (cumulative compound action).

All reversible machines have to run with the brushes set at the correct neutral. In machines having only one direction of rotation advantage can be taken, if commutation allows, of the above action in order to obtain slight compounding. In all cases, whether the machines work with the brushes at neutral or not, the finding of the correct neutral position of the brushes as a starting point for the setting of the brushes is of paramount importance in all interpolar machines.

As a rule, the location of the correct neutral position is undertaken for one brush only, and the rocker arm is then shifted until one brush center coincides with this line. The other brush studs will be in the right position provided the machine is perfectly symmetrical. It will be well, then, to check the symmetry of the machine before determining the neutral position for one brush. It is assumed that the armature has been checked and found free from short-circuits, grounds or open-circuited coils; that the shunt and series coils are expected to give alternate polarity, and that no series coil is opposing a shunt coil when all the others are adding to their respective shunt coil. The variation in voltage-drop for a given current in every shunt coil does not exceed 10 per cent., and the air-gap is the same under all poles.

It will further be necessary to check the distance between adjacent main-pole tips to see if they are properly spaced all around and to check the distance between main-pole tip and adjacent interpole tip to see if they are equal. This can be easily done by means of an ordinary pair of calipers.

Brush spacing is of utmost importance and usually neglected. To space the brushes cut a strip of paper to the length of the commutator circumference. Place the strip around the commutator and make the ends touch each other. Divide off on the strip of paper equal divisions corresponding to the number of main poles and place the paper on the commutator again, making the brushes of each stud toe the mark. If there is any doubt as to the symmetry of the machine, it will pay to obtain the no-load field curve shown in Figure 4.

METHODS FOR FINDING NEUTRAL POSITION

The following methods may be and are employed in finding the neutral position:

1. With fields excited, the machine is driven as generator without any load, a voltmeter being connected between a consecutive positive and negative brush. The rocker arm is

shifted until the maximum voltage is read on the voltmeter. The neutral position corresponds to the position of maximum voltage. Owing to the fact that the flux tapers off between the poles, as in Figure 62, hardly any difference will be noticed on the voltmeter when the brushes are shifted from the position *AA* through the neutral *NN* to the position *BB*.

2. The same objection attaches to the following method: The machine is run free as a motor, the rocker arm being shifted and the speed read on a tachometer. The position of minimum speed corresponds to the neutral position. Outside of the inaccuracy of a high-voltage voltmeter or a tachometer, there is the danger always present that the rocker arm may be shifted so far in the field that the generator will flash over or the rocker arm may slip and the motor run away.

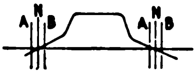


Fig. 62.—No-load field curve for interpole machine.

3. Another method consists in running the machine as a motor in both directions, the field current being kept constant until the speed is the same for either direction of rotation. Owing to the fact that the voltage varies between the different readings and that many trials are necessary, this method consumes much time. When this method is used, the brushes ought to be well worn in with but little play in the brush-holder box.

4. In the kick method, with the armature stationary and preferably the brushes removed from the cummutator, the shunt coils are opened and closed in quick succession. A millivoltmeter is connected to two copper points which are held against the commutator, the points being one pole pitch (or the commutator circumference divided by the number of main poles) apart. The zero reading on the voltmeter indicates the neutral position. This method is based on the fact that if an armature is placed in an alternating flux, such as is shown in Figure 63, for instance, then the emfs. due to the pulsation of the flux *N* are adding up along the line *AA*, and in a line *BB* perpendicular to the pole axis the difference in potential is zero. The objection to this method is that because of

the slots in the armature the reluctance of the path to the flux varies with the position of the armature relative to the poles, and a different neutral is obtainable by turning the armature slightly.

5. The following method obviates this last objection: The machine, the brushes of which are to be set is driven as a generator by means of an auxiliary motor, the fields being excited. The brushes are preferably all lifted from the commutator. Two contact wires *VW*, separated by about $\frac{1}{8}$ in., are connected to a millivoltmeter and applied to the commutator about the neutral zone. The contacts are shifted until the millivoltmeter reads zero (see Figure 64).

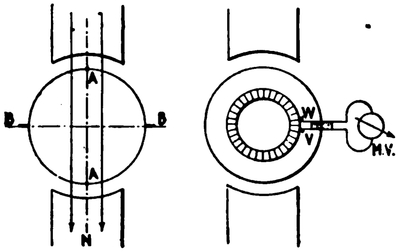


FIG. 63. FIG. 64.

FIGS. 63 and 64.—Diagrams referred to in methods 4 and 5 for finding neutral position

Between the points *VW* we read the emf. generated by rotation in the turns lying between these points. This emf. is proportional to the local field strength. In the neutral zone the field strength is zero, hence the zero indication on the voltmeter gives the neutral zone.

If it is not practicable to lift the brushes, the neutral position can be obtained with the brushes down and the rocker arm shifted to the so-found neutral. After this is done a new neutral is found. The actual neutral undisturbed by circulating currents under the brush, due to wrong brush position, may be found by few trials.

AN ANALYSIS OF BEST COMMUTATION UNDER THE BRUSHES AND A STUDY OF THE ACTION OF INTERPOLES BY BRUSH-POTENTIAL CURVES

The shape of the field curve in the neutral zone is rather flat, as can be seen from Figure 65, which has been obtained on a four-pole interpole machine having an equal number of main poles and interpoles. The curves have been taken by driving the armature in a clockwise and counter-clockwise direction of rotation. The neutral zone, as shown by the millivoltmeter and two points spaced one-eighth inch apart, is not the same for both directions of rotation. If the machine under consideration is a reversing motor, it will be well to determine the neutral for both directions by methods already described and set the brushes between the two neutrals found in this manner.

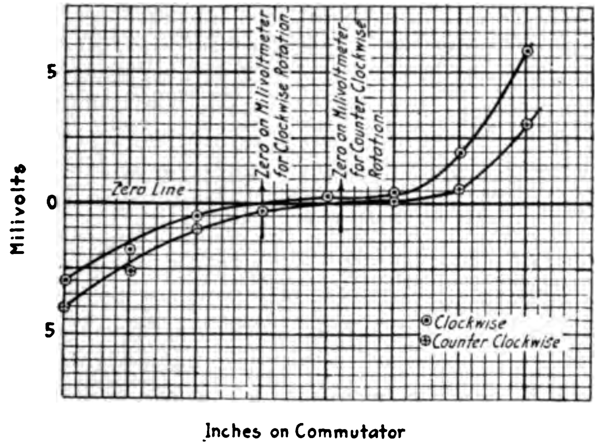


FIG. 65.—Field curve for four-pole machine having equal number of main poles and interpoles,

DETERMINING BEST COMMUTATION UNDER BRUSHES

Having found the neutral position, the next step is to determine if the machine commutates with a minimum loss under the brush, this being the best commutation. The fact that a new machine operates without sparking at the brushes does not prove that the commutation is the best possible, for it is known that liberally proportioned machines can operate for several weeks without sparking or blackening at the commutator, when, gradually, sparking or blackening develops with the resultant rapid wear of brushes and commutator. The large speed variation between no load and full load and pumping action in motors may also be due to wrong proportions of the interpole winding, and it becomes necessary to check whether the interpole winding and interpole circuit are proportioned to give best operation. A short review of the commutation process will help one to understand better the method used in arriving at a just appreciation of the points that have been enumerated.

Referring to Figures 66*a* and 66*b*, assume that the commutation of the current from the value $+J$ to $-J$ takes place in a resultant field of zero intensity, and that the resistance of the coil i' and the leads to the commutator is negligible compared with the contact resistance between the bars and the brush. The current $2J$ will distribute itself in inverse proportion to the resistances between the bars a and b and the brush, or in proportion to the areas of contact. The currents $i'a$ and $i'b$ in the leads to bars a and b, being proportional to the surfaces of contact, it follows that the current density under any point of the brush will be the same. Assuming uniform contact resistance over the brush surface, the drop of potential, which is proportional for any point under the brush AB to current density times contact resistance per square unit, will be the same.

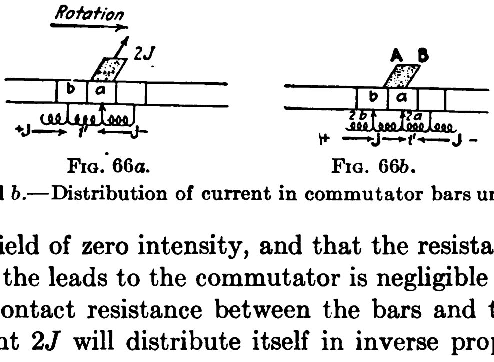


FIG. 66*a*. FIG. 66*b*.

FIG. 66 *a* and *b*.—Distribution of current in commutator bars under a brush.

If a millivoltmeter is connected then to two contact wires *M*, *N* (see Figure 67), and point *M* applied to the brush and point *N* successively to points 1 to 6 on the commutator, as shown in Figure 67, the same difference of potential will be read. Plotting these readings in Figure 68, we obtain for a negative brush the straight line *xy*. The drops in voltage are for a negative brush positive because the potential of the brush is higher than the potential of the commutator copper.

In the case considered, the current in the middle coil Figure 66 dies down at a uniform rate from the value $+J$ to zero value at a point corresponding to the middle of the brush, and rises then to the value $-J$ by the time the short-circuit is opened. This is the ideal or straight-line reversal. The experiment described can be performed with the simplest means and under the most adverse test conditions. Its findings give a very valuable indication showing the performance at the commutator.

The curve shown in Figure 68 corresponds to ideal commutation and is only approximated in practice. Commutation in a uniform field, void of magnetic flux, is practically impossible. The armature winding tends to set up a magnetic field when carrying current and the short-circuited coil carries with it in space a magnetic field of varying magnitude during the process of commutation. It is the function of the interpole to cancel these fluxes and produce a commutating zone void of flux, as explained above.

If the corrective action of the interpole is insufficient, then the coil while under the brush tends to carry current in the same direction as before its terminals were short-circuited. The current i'' (double-arrowed current in Figure 69) adds itself to current i' (single arrow in Figure 69) and increases the current in the lead *ia* and the current density under the brush tip *B*. It decreases the current in the lead *ib* and the brush density at the brush tip *A* (see Figure 69).

Still assuming uniform contact resistance, the voltage drop at the brush tip *B* will have increased, while at brush *A* it will have decreased. The drop in voltage along the face *AB* of the brush taken with a millivoltmeter, as described in Figure 67, will be lower at A and higher at B, and will have along AB the shape shown in Figure 70. The difference in voltage MN sends a circulating current through the brush which is limited only by contact resistance between brush and commutator, the resistance of the leads ia, ib and the resistance of the coil. All these resistances being relatively low, a very heavy circulating current will be allowed to flow. At the instant the brush leaves the bar a this heavy current is suddenly interrupted. As long as the energy consumed in the opening spark stays below certain limits, depending upon the grade of the brush, and which, according to recent tests, seems to be about 5 watts per centimeter length of brush, the sparks are small, hardly perceptible and not very destructive. The commutation shown in Figure 70 is the result of too weak an interpole, and it is said that the machine is under-compensated.

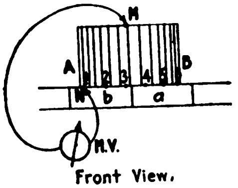


FIG. 67.

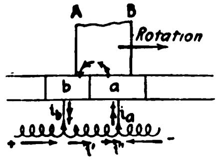


FIG. 69

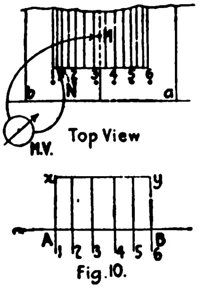


FIG. 68.

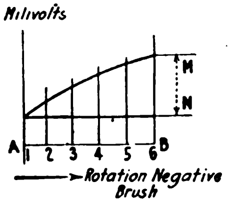


FIG. 70.

FIGS. 67 to 70.—Voltage drop for negative brush during commutation when interpole is too weak.

Provided the section of the interpole proper is ample and the magnetic circuit of the interpole is not saturated, a reduction in the air-gap under the interpole by addition of sheet-iron shims will materially help to improve commutation. The addition of more turns of the interpole would be the next step toward correcting the trouble. If the magnetic circuit is saturated, then a reduction in face area of the interpole, by cutting down the edges in a tangential direction, will bring relief through increasing the magnetic induction in the air-gap, while the total interpole flux continues to be constant.

STUDYING ACTION OF INTERPOLE BY BRUSH-POTENTIAL CURVES

The conditions just described are very much accentuated if the interpole is reversed, for then the interpole flux, instead of tending to produce a neutral zone, adds its flux to the armature reaction flux and the flux of the short-circuited coil. The brush-potential curve shown in Figure 71 depicts the condition under the brush with a reversed interpole and is a very good indication of this trouble. In taking the curve the millivoltmeter reverses its reading while we move the contact point along the brush in the direction of rotation. If the interpole flux is too strong, then the coil while under the brush tends to carry current in the direction after the commutation has been completed. This action is shown from Figure 72, where the current i' (double arrow) produced by the excess interpole flux is increasing the current density under the bar *b* or leading brush tip *A*, and decreasing the current density under bar *a* or trailing brush-tip *B*. For a negative brush the brush-potential curve, taken as explained by means of Figure 67, will have the shape shown in Figure 73. This action of the interpole is expressed by saying that the machine is over-compensated. If the machine is very much over-compensated, the brush-potential curve will take the form shown in Figure 74. For a negative brush and taking the readings under the brush in the direction of rotation, the millivoltmeter readings may change from a positive value to a negative value.

It is a matter of experience that a slight over-compensation is helpful in obtaining sparkless commutation. It has also been observed that a machine can stand much more deviation from compensation for constant-current density under the brush when the machine is over-compensated than when the machine is under-compensated. This is explained by the fact that with under-compensation the current density is increased at the leading brush tip *B* (see Figure 69) or at the tip which breaks the circuit of the short-circuited coil, while with over-compensation the current density is lowered at the leading brush tip *B* (see Figure 72).

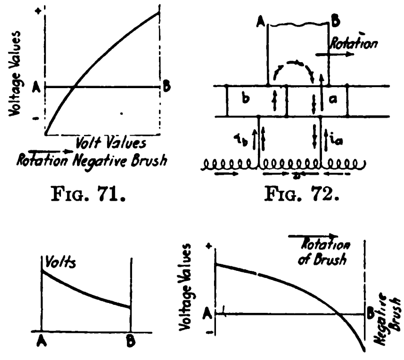
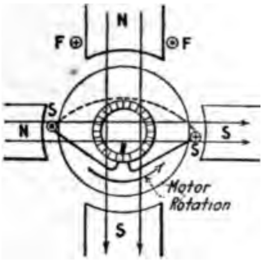


FIG. 71. FIG. 72.

FIG. 73. FIG. 74.

FIGS. 71 to 74.—Brush-potential curves, showing action of reversed interpole and over-compensation.

Over-compensation is most harmful in machines working with a weak main field, such as adjustable-speed shunt motors at the higher speeds. Referring to Figure 75, which represents the case of motors running counter-clockwise, we find the direction of current generated by rotation under the interpoles in the short-circuited coil *SS* by means of the Fleming rule, for instance. Since we have assumed over-compensation, this will also be the direction of the resulting current in the short-circuited coil in *SS*. We notice that the coil *SS* tends to produce a flux opposing the flux at the main-pole field coil *FF*. In consequence we have, when the load is thrown on, the same action as in a differential compound motor. Figure 76 shows the speed of the motor in function of time after the load is thrown on the motor, in case the conditions of the magnetic circuit, the electric circuit and the load are such as to damp out the first increase in speed due to the action of the short-circuited coil. If, on the other hand, conditions are unfavorable,



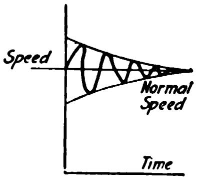
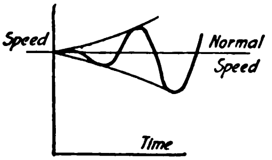


FIG. 75. FIG. 76.

FIGS. 75 and 76.—Direction of current in short-circuited coil under interpole, and speed-time curve after load is thrown on.



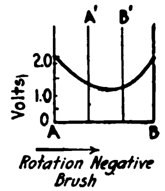


FIG. 77. FIG. 78.

FIGS. 77 and 78.—Speed-time curves under unfavorable conditions, and brush-potential curve for wide brush.

the original impulse is strengthened and the speed-time curve takes the shape shown in Figure 77, the motor operation becomes unstable, and the machine "pumps." The same phenomena repeat themselves which have been previously described in connection with a backward shift of the brushes from the true neutral position. The danger of unstable operation is increased the weaker the main field and the greater the inertia of the armature and load connected to same.

Further conditions affecting instability are:

1. Ratio of armature ampere turns to field ampere turns. Any increase in this ratio will increase the liability to pumping (or hunting, as it is sometimes called).

2. Saturation of main magnetic circuit. The lower on the saturation curve the motor works the greater the danger of instability.

3. The greater the ratio of self-induction to resistance (including rheostat resistance) in the shunt winding, the less danger of instability. Hence increasing the size of the shunt-field wire without changing the number of turns will reduce the tendency to hunt.

A few turns of compound winding will effectively oppose the tendency of the short-circuited coil to weaken the main pole. Many interpole motors now on the market have such a winding on the main pole—this winding being called a stabilizing winding. Short-circuited sleeves around the interpole are of little value, in the writer's experience.

All motors showing a rising-speed characteristic from no load to full load at any speed will be in danger of being unstable in operation, and for this reason it should be required from any machine working with field weakening to show a dropping-speed characteristic at the high speed between no load and about 50 per cent. overload. The remedy, if we find the machine over-compensated, is obvious. Increase the interpole air-gap if possible. Take some of the turns off from the interpole if this can be easily accomplished. It is not recommended to shunt part of the interpole current through a resistance. A non-inductive resistance should never be used where the load is sudden and fluctuating, as in railway generators for instance.

It sometimes occurs that an interpole machine operates quite well at light loads but sparks badly at over-loads. If the brush-potential curve obtained at light load has the shape of Figure 73, indicating over-compensation, while the brush-potential curve obtained at overload has the shape of Figure 70, indicating under-compensation, it is a sure sign that the interpole magnetic circuit is saturated and probably the section of the interpole too small. Cutting down the face of the interpole in a tangential direction will help. If the distance between main and interpole tip is small, this will at the same time reduce the interpole leakage and thus further improve commutation.

With wide brushes the brush-potential curve sometimes takes the shape shown in Figure 78. If sparking occurs, it can be reduced by reducing the width of the brush from *AB* to *A'B'*, provided the current density under the brush is not unduly increased by doing that. The brush-potential curve is also valuable in cases where the unit is large, making it impracticable to test the machine under full-load conditions. All that is necessary is to take the brush potential curve with the armature short-circuited, the fields being just enough excited to send full-load current through the armature and interpoles. The same applies to high-voltage machines where it would be dangerous for the operator to take brush-potential curves under full-voltage condition.

Owing to the different distribution of leakage flux under full-field condition, this is theoretically not quite correct, though it is quite close enough for practical work.

METHOD OF OBTAINING BRUSH-POTENTIAL CURVES

The following procedure has proved satisfactory in taking brush-potential curves: Since the shape of the curve is the point of interest, in order to facilitate comparisons it is advisable always to take the curve at the brush, the potential of which is higher than the potential of the commutator—the negative brush in a generator, for instance, and the same rotation (clockwise in the above curves). To take the curve two copper needles can be used, but two ordinary writing pencils well sharpened have proved very useful for the purpose.

A strip of cardboard paper, perforated with holes about one-sixteenth inch in diameter and spaced about one-eighth inch apart, will do good service in obtaining the points on the curve.

The strip can be laid over the commutator surface and fastened to the two brush-holder studs adjacent to the brush under examination. A uniform pressure on the contacts is desirable for obtaining most consistent results. If the curve is taken as suggested at the negative brush, care must be exercised to apply the positive terminal of the millivoltmeter to the brush and the negative terminal to the commutator copper. A positive reading on the voltmeter will be plotted as a positive ordinate. If the voltmeter leads have to be reversed the reading will be plotted as a negative ordinate.

In the deduction of the brush-potential curves it is assumed that drops in voltage between commutator and brush are proportional to the local current density. This is only true in the case of ideal commutation, for then the density is constant under the brush. As a matter of fact, the drop in voltage is not proportional to the current density; but if we should plot the drop in voltage against the current density we should obtain a curve approximating a hyperbola, the drop in voltage becoming constant when the current increases indefinitely.

Furthermore, we have to keep in mind that the current density varies along the brush not only in space but also in time. In consequence, we cannot attribute any quantitative significance to the brush-potential curve and cannot from the brush-potential curve construct the curve of distribution of current density under the brush. The disparity between the actual distribution of current density and the distribution deducted from the brush-potential curve will be the greater the more the commutation departs from the ideal commutation with constant-current density over the entire surface of the brush. Still, as a qualitative judgment of commutation, the brush-potential curve is an invaluable asset of the operating engineer. Qualitatively, all the above deductions stay, in spite of the fact that the assumption of uniform contact resistance between commutator and brush is incorrect. But it should be kept in mind that the better the commutation, the more nearly correct these curves are.

No attempt has been made in the above discussion to enter into the mathematical theory of commutation, for those interested in this matter will find articles on this subject in technical literature by eminent electrical engineers.

BRUSH POSITION ON NON-COMMUTATING POLE MACHINES

The location of the neutral position of the brushes on the commutator and the operation of non-commutating pole machines presents a widely different problem from that just treated in the previous articles on operation with interpoles, sometimes called commutating or auxiliary poles. The one great difference lies in the fact that on the commutating pole type, the neutral point is fixed for all conditions of load from zero to full-rated load, while on the non-commutating pole machine, the neutral point on motors as well as generators shifts with every change of load.

On the manufacturers' test floors, the brushes are first placed on the mechanical or no-load neutral determined by locating a point on the commutator equidistant from the pole tips of two adjacent poles. Well-designed machines require very little shift from this position even though the neutral point moves very appreciably with changes of load, because of the fact that the brushes fitted on such machines have sufficient transverse resistance to minimize the short-circuited currents caused by unequal potential between the two sides of the brush at the commutator surface. Where shifting is necessary on account of sparking produced by the moving of the neutral point due to the cross magnetization of the armature conductors, the amount of the shift must be determined by trial. On the test floor these trials are continued until the neutral has been found which results in the most successful commutation, or, where the sparking cannot be entirely eliminated at both no load and full load, which produces the best average condition over the entire range of operation. It is recommended that the machine be operated with the brushes at the position producing the best average commutating conditions rather than resorting to a continual shifting of the brushes to suit the load requirements as in the latter method, the fit of the brushes on the commutator is being constantly changed resulting in sparking and blackening of the commutator surface. Then, too, there is the probability of having the load suddenly drop after the brushes have been shifted to produce perfect commutation at full load with the result that serious sparking, damaging both brushes and commutator, will occur.

On a motor, the brushes should be shifted backward or against rotation when sparking begins to appear as the load increases, returning the brushes to their original position as the load decreases again. With the two brush position limits determined at no load and full load, an average point may be easily found by shifting, which gives the best commutation over the entire range. If the direction of rotation is changed, it is necessary to place the brushes on the opposite side of the neutral point, the same distance as that previously obtained to secure satisfactory results. It is necessary where reversals are frequently made, to place the brushes on the no-load neutral so as to eliminate their continual shifting. A motor designed for rotation in one direction only, when applied to a service requiring frequent reversals may spark continuously if operated with the brushes on the no-load neutral. This difficulty may be overcome, however, by increasing the air gap by removing shims or liners from between the pole pieces and the frame thus reducing the effect of the cross magnetization of the armature conductors, resulting in less shifting of the neutral. It should be remembered, however, that an increase in the air gap will be accompanied by an increase in speed requiring a strengthening of the field current. An excessive shift of the brushes against rotation on a motor will produce a rising speed characteristic as the load is increased due to the increase of the demagnetizing effect of the current in the armature conductors upon the main-pole flux. The manufacturer should be informed, when a motor is being ordered, whether or not reversed operation is to be required as the design of the machine will be materially different with respect to the fields, brushes and brush holders.

The shifting of the brushes from the no-load neutral point on a generator to prevent sparking as the load is increased is exactly opposite to the procedure in the case of a motor. In the generator, the shifting is in the direction of rotation and the same method is adopted for locating the best average operating position as previously described for the motor. The no-load and full-load brush positions may in some designs be so far apart that no satisfactory average position can be obtained. In such a case, an increase in the air gap will reduce the maximum brush shift necessary to such an extent as to make it possible to obtain a good working neutral. The decrease in voltage occasioned by the increase in the air gap must be overcome by increasing the strength of the field current. It is not usually necessary to change the air gap where the generator is operated within its normal rated limits providing that correct adjustments have been made at the factory. If such adjustments have not been made or if it is desired to operate the generator at above its rated capacity, since the temperature rises permit an increase in load, the commutation constants may be materially improved by the increase in air gap.

BRUSH DEFECTS CAUSING FAULTY COMMUTATION

Choice of Brushes—Brush and Contact Resistance—Brush Density—Unequal Brush Spacing Around Commutator—Incorrect Brush Angle—Wrong Brush Pressure—Misalignment of the Brush-holder Brackets—Brush Chatter—Brushes Binding in Holders—Brush Wear—Glowing and Pitting of Brushes—Loose Connections: Burnt-off Pigtails—Vibration of the Brush Rigging

CHOICE OF BRUSHES

Successful commutation depends to a large extent upon the selection of the brush to suit the demands of the service. Manufacturers of brushes for electrical machinery vary widely in their recommendations and oftentimes troubles from faulty commutation, as well as troubles with commutators come as a direct result of the operator following out instructions and recommendations made by brush agents. Experience with the various types of brushes is undoubtedly the best criterion in the selection, but manufacturers of electrical machinery should be consulted wherever possible before a change in the brush equipment of a machine is made, as the design of the unit should be considered.

While machines are shipped with the proper brushes attached for operation under ordinary conditions, it frequently happens that local surroundings, with which the manufacturer is unacquainted, make necessary a complete change of the brush equipment for successful operation. For example, units exposed to oil vapors should never be equipped with graphite brushes for the reason that the additional lubrication caused by the oil will unite with the graphite and coat the surface of the commutator with smut, causing serious sparking. This smut may be removed by wiping the commutator with clean canvas, but unless continuous attention is given, the sparking will reappear. In oil-laden atmospheres, dry-carbon brushes should be substituted as they will absorb the oil condensing on the commutator and run very smoothly. Therefore in cases of this kind where the operating conditions in regard to the brushes are unusual, the attention of the manufacturer should be called to this fact when electrical machinery is being ordered.

Graphite brushes should never be used where the side mica on the commutator is flush with the surface, as in a short period of time sparking and brush wear will result due to the failure of the brush to wear the mica at an equal rate with the copper. Graphite brushes should not be used even though the side mica be undercut, where the machine is exposed to acid or alkali fumes or other corrosive agents, unless the brushes have abrasive material in their composition which will cut through the insulating film caused by the fumes and insure a good contact with the commutator surface. Graphite brushes usually will not operate successfully on high-speed commutators when set trailing on account of heating but will, however, produce good results when set leading at an angle of fifteen degrees or more.

In general, carbon brushes are employed where the special requirements of the service make graphite brushes inadaptable. There are several disadvantages which are inherent in the carbon brush and limit its field, such as its high coefficient of friction, low current-carrying capacity, lack of lubrication and its tendency to chatter. The carbon brush can be used at any angle and is peculiarly well fitted for operation in special cases, as mentioned above, where the surrounding air is oil laden or filled with acid or alkali fumes.

Graphitized carbon brushes will operate successfully at any angle and will give satisfactory results for most commercial applications. The side mica on the commutator must be grooved or under cut since this type of brush contains practically no abrasive material. They require no lubrication and will not commutate perfectly where oil is present, on account of the formation of smut on the commutator surface. When a new set is installed, it is necessary to wipe the commutator frequently with clean canvas for a few days, to remove the excess lubricant inherent in the brush. Composition brushes containing metal, known as metal graphite brushes are used on collector rings on 3-wire generators and on commutators of electrolytic machinery where very high currents, up to thousands of amperes, with voltages of ten and below are generated. Here the use of metal brushes is permissible because the voltage between commutator bars is very low and high current-carrying capacities in the brushes are required as well as low-voltage drops in the contact and brushes. The high current densities required, from seventy-five to eighty-five amperes per square inch, are necessary in order to decrease the size of the commutator to dimensions which are mechanically possible in construction. The low contact and brush drop, under one volt, is essential because of the low voltage generated. Using other types of brushes, the brush and contact drop would amount to from two to three volts, which in this case would be a large percentage of the total generated voltage. The metal graphite brush has a low transverse resistance as compared with carbon and pure graphite brushes and for this reason in its substitution for other types, a thinner brush should be installed, if underbrush sparking, glowing and pitting appear, as the trouble will be due to the fact that the low-resistance brush is short-circuiting too many armature coils. When commutation trouble develops after metal brushes have been substituted, it is not necessary to keep the machine out of service while new holders are being secured to accommodate the thinner brush, for a temporary adjustment of the thickness may easily be made by filing off the toes or heels of the brushes without changing the holders. The center line of the brushes, however, after the filing, has to be shifted until it coincides with the same point on the commutator as intersected by the original center line.

Graphite, graphitized carbon and carbon brushes are used on direct-current machines, where the voltages carried vary from ten to thirty-five hundred volts. Where the voltage generated drops below ten volts, metal graphite brushes should be installed.

A brush should be free from air holes and foreign matter and its ingredients should be thoroughly mixed to insure uniformity. All of the brushes on the commutator should be of the same quality since an inequality will produce selective commutation due to the hogging of the current by the good brushes. An exception to the general rule is sometimes found in the case of electrolytic machines where carbon brushes are fitted to cut through the film caused by the fumes. If no lubrication is supplied these carbon brushes will chatter and it is customary to substitute a sufficient number of graphite brushes, so arranged on the various studs as to cover the entire commutator surface at each revolution and supply the necessary lubrication.

BRUSH AND CONTACT RESISTANCE

The resistance of the brushes and of the contacts between the brushes and the commutator directly affects the speed of a motor and the voltage regulation of a generator In the case of a motor, a drop in speed will result as the load comes on when any resistance is placed in series with the armature. This decrease of the speed will be directly in proportion to the amount of the armature resistance. For example, if the sum of this resistance in series with the armature and the resistance of the armature itself is represented by R, the applied voltage upon the armature being E and the current C, the actual voltage produced by the revolutions of the armature is E equals CR. Now if in another case, a total resistance of R_x was used and the applied voltage and current remained the same, the actual voltage produced by the revolutions of the armature would be E equals CR_x. Therefore if the CR_x of the second case is greater than the CR of the first, the speed of the motor will be less. The action in the case of the generator will be the same except that the voltage regulation will be affected instead of the speed.

The drop at the contact is very large as compared with that due to the resistance of the brush itself, in fact the brush resistance in this comparison is almost negligible. For example, referring to curve 4 on Figure 79, the contact drop with 45 amperes per square inch of contact surface is 1.2 volts for each polarity, making a total of 2.4 volts drop. The total drop including that due to the brush resistance, will be approximately 2.67 allowing a brush drop of 0.135 volts for each polarity. Figure 79 gives a set of 12 curves for the standard brushes on the market showing the drop in volts for each polarity or side with varying brush densities at the contact surface.

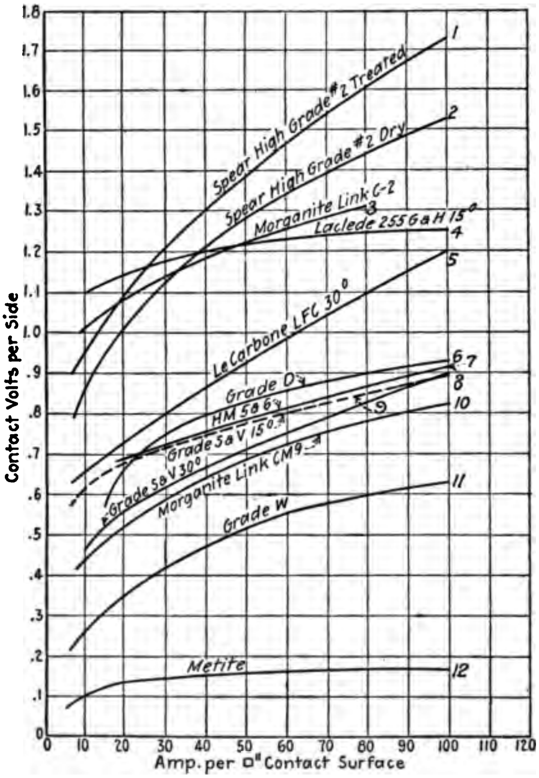


Fig. 79.

The values used in plotting the curves in Figure 79 are based on good contact secured by perfect brush fit. If the contacts are poor, due to improper brush fits, dirty surfaces or wrong spring pressures, the contact drop will be materially increased while the drop due to the resistance of the brush itself will remain practically constant.

In generators where the voltage must be held constant, it is necessary to compensate for this increased drop due to the resistances of the contacts and brushes by adjusting the strength of the shunt or series fields, by means of a hand rheostat, in the shunt field or an adjustable resistance in multiple with the series field. In the shunt generator the decrease in voltage due to this drop is easily remedied by increasing the shunt-field strength. In the compound-wound generator, where the drop in voltage is cared for by increasing the strength of the series field, the automatic voltage regulation from no load to full load is materially changed as a stronger series field always results in a greater hump in the compounding curve, that is, the departure from a straight line drawn between the no-load and full-load points becomes considerably larger at fractional loads. It is therefore important that this contact and brush drop be reduced to a minimum so as to prevent the necessity of strengthening the series field to compensate for this drop.

BRUSH DENSITY

Brush density is measured at the contact between the brush and the commutator surface and is expressed in amperes per square inch. In the measurement of the contact area the angle of the brush must be taken into consideration, for the length of the commutator span will naturally be greater than the thickness of the brush. When a fifteen degree angle is employed, the area of the contact surface will be 1.06 times the cross sectional area, with a twenty degree angle, 1.09 and with a thirty-seven and one-half degree angle, 1.25; all angles of course being measured from a vertical line through the center of the brush.

The entire current is carried by the brushes of each polarity. For example, in an 8-pole machine, the current should be divided equally between four sets of brushes. The current-carrying capacity of the brush varies with its composition, a carbon brush being used to carry thirty-five to forty amperes per square inch when required at times to handle a 50 per cent. overload for two hours, or forty to forty-five amperes per square inch where the overload is 25 per cent. for two hours. For continuous duty, where the load is constant over long periods, carbon brushes should not be run with a density exceeding forty-five amperes per square inch. Graphite brushes will operate satisfactorily with a brush density of fifty to fifty-five amperes per square inch when required to carry a 50 per cent. overload for two hours, fifty-five to sixty amperes when the overload is 25 per cent. for two hours and up to sixty amperes per square inch when the current is constant. Composition brushes made up of carbon, graphite and metal are fitted on machines whose duty cycle requires continuous service with a fixed current where the brush density may be run at values up to seventy-five amperes per square inch. Copper gauze or copper leaf brushes will handle a density of one hundred to one hundred fifty amperes per square inch successfully, but are used on collector rings only.

Assuming a total current of fifteen hundred amperes, carried by eight studs, with five one and one-fourth inch by one inch brushes at an angle of thirty-seven and one-half degrees, the brush density can be computed to be forty-eight amperes per square inch from the formula

$$\frac{C}{S \times W \times T \times A \times N} = D$$

where,

C = Total current in amperes.

S = Number of studs of each polarity, or the number of poles divided by 2.

W = Width of the brush in inches.

T = Thickness of the brush.

A = Constant corresponding to the brush angle, 1.25 for $37\frac{1}{2}$ degrees, 1.08 for 20 degrees and 1.06 for 15 degrees.

N = Number of brushes per stud.

D = Density in amperes per sq. in. of constant area.

$$D = \frac{1500}{4 \times 1\frac{1}{4} \times 1 \times 1.25 \times 5} = 48 \text{ amperes per sq. in.}$$

When it is desired to change the type of brushes used, and the best operating density of the new type is known, the number of brushes which will be needed may also be found by use of the above formula.

When brushes are operated for any great length at densities exceeding the values given above, disintegration due to heating will result. Should the overload current on the brush become two and one-half to three times as great as the normal capacity, the brush would become red hot and disintegrate very rapidly. Where a machine operates continuously under its rated ampere load, its efficiency may be increased by removing a percentage of the brushes until the proper density has been established. The gain in efficiency is effected by the reduction in brush friction.

UNEQUAL BRUSH SPACING AROUND COMMUTATOR

Symptoms—Sparking at One or All Studs.
Selective Commutation.

To secure satisfactory commutation it is necessary that the brushes be equally spaced around the commutator.

Unequal spacing of the brushes may cause sparking to occur under all of the brushes due to all of the different studs not being at the neutral points. However, the sparking may take place at only one stud or at any number of them while the neighboring studs commutate perfectly. This latter condition is caused by unbalanced circuits in the armature windings resulting from a larger or smaller number of commutator segments and armature conductors connected thereto, delivering an unequal voltage and current to the various sets of brushes. The current flowing in the armature circuits divides in proportion to the resistances of the circuits and if the brush spacing is such as to cause unequal resistances of these circuits due to differences in their length, the current distribution will be such as to cause a large current to flow in the shorter circuits and a small current in the longer circuits. Unbalancing of the armature circuits may also result from loose connections at the brushes or studs as described in the succeeding articles.

To obtain equal spacing, the studs should be set up with the brush holders in place, and the commutator should be wrapped tightly with a long strip of paper about an inch wide covering its entire circumference and tied in place. The lapping point of this paper should then be marked, the paper should be removed, spread on a flat surface and stepped off with a large pair of dividers or similar tool into exactly equal sections, equal in number to the number of poles. The strip should then be replaced on the commutator and the studs so adjusted that the toes of the brushes on the different studs just touch these marks.

Another method for obtaining the correct brush spacing is by counting off and making equal the number of commutator segments between studs. This method is relatively accurate in spite of the slight variation in the thicknesses of the mica and the segments, where the number of commutator segments is evenly divisible by the number of poles, which is the case in multiple-wound armatures. Where the armature is series wound and the number of segments is not evenly divisible by the number of poles, a certain amount of estimating is necessary to split up the odd segment and the resulting inaccuracy is liable to be the cause of poor spacing.

The above methods outlined for obtaining the correct brush spacing are applicable either to machines designed with or without commutating poles.

INCORRECT BRUSH ANGLE

Symptoms—Brush Chatter.
Binding in Holders.
Sparking.

Sparking of such a nature as to seriously burn the commutator surface and the brushes frequently results due to incorrect brush angle. Brushes are set on direct-current motors and generators in order to approach the commutator in three different ways, radially, leading and trailing, the two latter positions being illustrated in Figures 80, 81 and 82. The brush angle depends upon the commutator speed, the direction of rotation and upon the service requirements with respect to rotation in either direction.

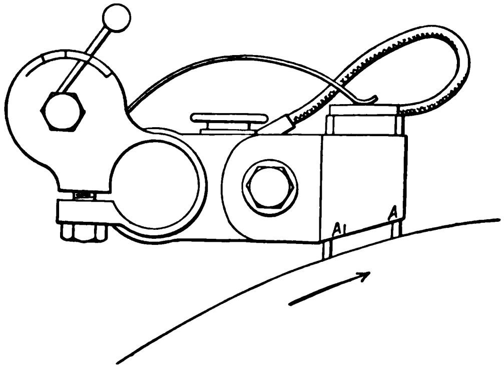


Fig. 80.—Leading brush.

Where the speed of the commutator, assuming one direction of rotation only, does not exceed 500 feet per minute, the brushes may be set leading at an angle of approximately fifteen degrees. With speeds ranging from 500 feet per minute to 2000 feet per minute, the brushes are usually set approximately fifteen degrees from the vertical trailing. Above 2000 feet per minute, the bushes are set 37½ degrees from the vertical, leading. Brushes whose angle with the vertical is greater than twenty degrees are commonly called large angle brushes.

Machines fitted with radial brushes can be reversed without danger of sparking. Machines fitted with brushes with an angle of twenty degrees or less may be reversed without serious sparking under emergency conditions but if the direction of rotation is to be permanently changed the brush holders should be reversed in position. When machines are designed to operate in one direction of rotation only, such as the motors, driving fans, pumps and line shafting, or generators driven by steam engines, turbines or water wheels, where large angle (above twenty degrees) holders are employed, reversal must not be attempted without a reversal of the brush holders.

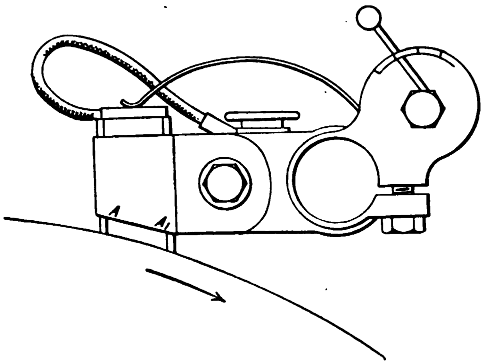


FIG. 81.—Trailing brush.

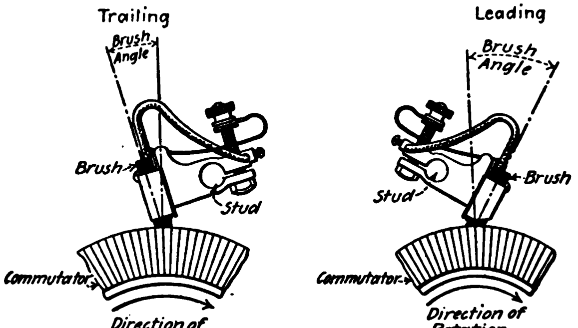


FIG. 82.—Correct position of brush on commutator.

Large angle brushes operated trailing will bind in the holders and cause a great deal of sparking as well as scoring of the commutator surface and breaking off of the toes of all brushes. The breaking of the brushes is due to the pressure of the commutator surface against the brush contact surface at a large angle resulting in an undue stress being set up by the brush against the holder. The sparking results from the brush not riding properly on the commutator caused by the sticking in the holder boxes and also from the carbon particles broken from the brush toes being carried around the commutator. Motors designed for continuous reversing, such as those driving planers and roller mills are usually fitted with brushes set at an angle of twenty degrees from the vertical for experience has shown that the brushes will operate at this angle under such service without changing the fit of the brush with each reversal and thus will produce satisfactory commutation. If a brush whose angle with the vertical is less than twenty degrees is employed for continuous reversing service, sparking will result due to the rocking of the brush in the holder, causing two separate brush fits. Brushes with an angle greater than twenty degrees will cause brush breaking and sparking as mentioned previously in this paragraph.

Where the reversal of the brush holders on the stud is required when the direction of rotation is changed, the stud must be shifted so that the brushes are again placed on the neutral point. Instead of redetermining this neutral point by experiment, it is advisable to mark a point on the commutator at the center line of the brushes in their original position before disturbing the holders and then bring the brushes back to this same position after reversal.

WRONG BRUSH PRESSURE

Symptoms—Sparking.
Brush and Commutator Wear.
Selective Commutation.
Poor Fit of Brushes.

When the pressure forcing the brush against the commutator is too great, sparking, brush wear, friction, excessive commutator wear and grooving, and crumbling of the brushes will result. Insufficient spring pressure will cause sparking, selective commutation, unbalanced circuits in the armature, and unsteady voltage. It is impossible to give a fixed value for the spring pressure that will hold for the many different kinds of brushes and holders upon the market but in this article on the wrong brush pressure, the troubles resulting from too much or too little pressure will be covered, no matter what the proper amount of spring tension may be.

Too much spring pressure on the brushes will cause them to bind in the holders, due to the combined action of the heavy pressure and the tangential force exerted by the commutator. The brush under such condition cannot follow the slight irregularities which always exist on the commutator with the result that sparking occurs and the brush may be fractured at the heel or the toe. Rapid brush wear and excessive wearing or grooving of the commutator as well as high temperatures from the undue friction are also directly traceable to too much spring pressure.

Insufficient brush pressure will cause sparking due to poor and irregular contacts and the shifting of the brush fit. Sparking will also result from the unbalancing of the armature circuits when all of the brush sets are not making uniform contact. This often happens on machines operated in horizontal positions since the total pressure of the brushes on top of the commutator is the sum of the spring pressure and that exerted by the weight of the brush, while at the bottom the effective pressure is the difference between the spring pressure and the brush weight. Selective commutation due to inadequate spring pressure, considered either from brush to brush on the same stud or from stud to stud of the same polarity, causes sparking on some or all studs, burning of pigtails resulting from an unequal distribution of the current and glowing of the brushes.

The pressure of the brush on the commutator should be sufficient to insure good electrical contact without causing undue friction or excessive wear of the commutator. As previously stated no fixed values for the spring pressure can be given to cover all conditions but in good commercial practice, a pressure of one and one-half to one and three-quarter pounds per square inch of contact area can be used with carbon brushes. This figure may be reduced to one pound per square inch of contact area where graphite brushes are installed. Once the proper value for the pressure has been determined, advantage should be taken of the adjustable features of the brush-holder spring and the proper tension maintained as the brush wears. The brush pressure per square inch of contact surface for the brushes on the collector rings of 3-wire generators is usually from four to five pounds.

Fig. 83.—A full set of brushes placed on a machine without proper fitting. Note the small percentage of actual contact surface causing overloading and sparking.

A poor fit of the brushes on the commutator will result in sparking, glowing and heating of the brushes and the commutator. Poor contact may be due to the brushes not being properly fitted to the surface of the commutator, insufficient spring pressure, hard spots in the brushes or metal particles being imbedded in the face of the brush or to the brushes being forced away or lifted from the surface of the commutator on account of foreign matter upon it, such as hardened lubricant.

When the commutator surface has been freshly turned, it will not be possible to secure good commutation and a good brush fit without first polishing the commutator. This is done by running the machine light for at least 24 hours with normal brush pressure and then an additional 24 hours under approximately half load. The complete treatment of the commutator and brushes under these conditions is given in the chapter on "The Starting and Operation of Direct-current Motors" on Page 73.

Sparking caused by a poor brush fit due to insufficient spring pressure is taken up in this article. Hard spots occur in the brushes due to the improper mixture of the brush ingredients. A brush defective on account of hard spots should be discarded and replaced by one whose quality will insure an equal distribution of the load. In some cases it is necessary to replace the entire set of brushes in order to obtain this equal distribution. The hard spot in the brush does not wear down at an equal rate with the rest of the brush and finally becomes the only point of contact resulting in glowing and pitting and under-brush sparking. Metal particles imbedded in the face of the brushes result from the use of sandpaper or grinding stones applied to the surface of the commutator with the brushes down. These metal particles will cause under-brush sparking, glowing and pitting and also spoil the commutator

Fig. 84.—Copper imbedded in the surface of the brushes caused by sandpapering the commutator with the brushes down.

polish. When excess lubricant is applied to the commutator, it will combine with dust and lint and roll up under the brushes, causing poor contacts resulting in burning, pitting and sparking.

The brushes should not be fitted to the surface of the commutator by drawing strips of sandpaper back and forth under the brush but the sandpaper should be drawn under the brush in the direction of rotation with the spring lifted between cuts. Brush fitting is discussed in detail in the chapter on "Erection and Assembly" on Page 53.

MISALIGNMENT OF THE BRUSH-HOLDER BRACKETS

Symptoms—Sparking at One or More Studs.
Glowing of Brushes.

Sparking may occur under the brushes of one or more studs if the brush-holder brackets are not properly lined up with the commutator segments. In case of this misalignment, all of the brushes of the stud which is out of line will spark because they are short-circuiting a greater number of commutator segments and armature conductors than the design of the machine will permit, since coils outside of the neutral zone may be included. Improper alignment can be readily detected by noting if all of the toes of the brushes of one stud are in line with one edge of a commutator segment.

Misalignment of the brush-holder bracket may result from the loosening of bolts or from the distortion of the insulating collars, through warping or swelling, produced by heat or moisture, or both. Where there are ten or more brushes on each stud or bracket, it is necessary to support the outer end by the use of tie rings made of wood or fibre and misalignment is frequently due to the tightening of the bolts holding these tie pieces to the ends of the studs before the brush spacing has been determined. The correct alignment and spacing of the brushes and brackets should be secured before the bolts holding the tie pieces are tightened up. It will be found that the tie pieces are fitted with slots to permit adjustment of the bracket position.

Where sparking occurs at one stud only it is advisable to check the brush spacing and alignment. The brackets or studs must also support the brush holders so that the inner and outer holders are at the same distance from the commutator surface.

BRUSH CHATTER

Symptoms—Hissing Noise.
Ring Fire.
Disintegration of Brushes.
Mechanical Sparking.

Brush chatter, a very common and serious trouble in direct-current commutation is indicated by a hissing noise accompanied by sparking at the brushes. This sparking is of a mechanical nature, lacking the usual snap and bright burning arc peculiar to electrical troubles. Brush chatter can often be distinguished by applying a very small amount of lubricating oil or grease to the commutator by means of a piece of waste or cloth. For a short time, the hissing and sparking will disappear but within a few minutes, especially if the commutator is warm, the trouble will reappear. While the application of lubrication to the commutator may be resorted to as a test,

FIG. 85.—Fractured brushes as a result of brush chatter, due to high mica and a rough commutator surface.

continued use of the lubricant is not advisable and will perhaps result in the disintegration of the side mica and the smudging of the commutator surface. Besides the sparking and hissing, brush chatter, if allowed to continue makes itself known by the gradual crumbling away of the brushes and the loosening of the pigtail connections. An examination of the commutator may reveal no apparent cause for the action for perhaps the surface will appear perfectly smooth and bright.

Brush chatter is due in most cases to too much clearance in the holders. It can also be traced to the incorrect angle of the brush on the commutator, insufficient spring pressure, high mica, and the selection of the wrong brush for the service requirements. Too much clearance in the holders will permit the brushes to move around and chatter. This clearance should be from ten to fifteen mils. A remedy in such cases is wherever possible, to tip the brush holders or brackets so as to increase the angle of the brush from the vertical line through its center which causes the brush to ride against one surface of the brush-holder box continuously instead of rocking from one side to another. The angle of the brush on the commutator will affect its successful operation, as a leading angle of the brush of fifteen degrees on a commutator running from 500 to 2000 feet per minute will invariably cause chattering, while a trailing brush, whose angle is fifteen degrees from the vertical will operate without trouble. Where the commutator speed is below 500 feet per minute, a leading brush of fifteen degrees will perform satisfactorily while a trailing brush of the same angle will in some cases chatter slightly at this low speed due to the tendency of the brush to bind in the holder. Slow-speed commutators are generally fitted on generators directly connected to steam or gas engines, or on motors driving compressors or piston pumps, and the throw of the reciprocating parts will cause the armature and commutator to run out of true unless the bearings are continually adjusted for alignment. Brush holders set leading permit the brushes to follow the movement of the commutator affected by this throw, while a trailing angle will result in a sluggish movement of the brush.

When the commutator speed is greater than 2000 feet per minute the brushes are set at a leading angle of from twenty to forty degrees as a measure against chatter, but this angle cannot be employed where frequent reversals of rotation are required. Here an angle of twenty degrees is used. Insufficient spring pressure will allow the brushes to jump up and down in the holders. The remedy of course is to correctly adjust the tension of the spring and recommendations for the correct values to use are made in the article on Brush Pressures. High mica prevents the brush from riding smoothly on the commutator, which may be remedied by making the mica flush with the commutator surface by the use of fine sandpaper or by undercutting the mica slightly with a hack-saw blade. When the sandpaper is being used the brushes should all be raised and the machine carefully blown out before voltage is applied. For high-speed commutation graphite brushes should be used as dry, non-self-lubricating carbon brushes will cause chattering at high speeds with any angle.

BRUSHES BINDING IN HOLDERS

Symptoms—Glowing.
Sparking.
Mechanically Unbalanced Armature.
Burnt-off Pigtails.

When a brush does not move freely in its holder, sparking, glowing and heating of the brush will result. This trouble can usually be recognized by the glowing of the sticking brush and the very bright or snappy arc under it. The failure of this brush to take its normal proportion of the current will cause the remainder of the brushes on the stud to be overloaded which may result in the heating and burning off of the pigtails. When the pigtails or connections between the brushes and the brackets are destroyed, the only path remaining for the current is directly through the brush holder. Owing to the high-resistance contact between the box and the brush, sufficient heat will be generated to actually melt the metal parts and cause the brush and box to freeze or run together. Extreme cases of this nature may make it necessary to replace the entire set of brush holders and brushes or to file out the boxes, before replacement. During the action caused by the brush sticking in a generator, there may be a vibration of the voltmeter pointer and a slight drop on the ammeter due to change in the voltage, but as station meters are rather sluggish, flickering of the station lights may be a more sensitive indication of this trouble, if these lights are supplied by the generator in question. The sticking of the brushes in the holders may also cause the mechanical balance of the armature to be upset.

Fig. 86.—Scored commutator surface resulting from the brushes sticking in the holders and selective commutation. Note smooth bands where good commutation was observed.

On a motor, brush sticking will result in sparking and glowing and if the machine is operating in parallel with a lighting system, flickering of the lights may also be noticed due to the voltage variations resulting from the fluctuating load on the motor. If the overloading of the brushes on a stud resulting from sticking causes the pigtails to be burned off, there is danger of the burned-off section of the pigtail dropping on the commutator and causing a short-circuit which may flash the machine over. Short-circuits may also be caused by the melting of the solder used in connecting the pigtail to the brush, and its subsequent dropping on the commutator surface.

Brushes may stick in their holders due to defects in the brush or holders. The holders may not provide the proper clearance, which should not be less than ten to fifteen mils on all sides, due to damage received in handling. The brushes themselves may swell or expand when heated by the current or may also cause sticking due to irregular surfaces produced by plating or tinning.

Fig. 87.—A complete set of brushes having an excessive clearance in the holder permitting two or more fits on the commutator surface, resulting in sparking and high temperatures from the overloading of the brushes and contacts.

When a brush is first placed in its holder, care should be taken to see that it moves freely. Rough or high spots on its surface should be filed off and a similar treatment given to rough surfaces on the inside of the box. It is almost always advisable in cases where brush sticking is due to the swelling of the brushes under load, to immediately discard such a set of brushes as they will require constant attention and continually endanger satisfactory operation.

BRUSH WEAR

Symptoms—Rapid Wear of Brushes.
Commutator Grooving.
Mechanical Sparking.
Ring Fire.

Brushes have been known to wear down completely within a few days after installation. On the contrary, one generator is known to have operated practically continuously for sixteen years on its original set of brushes. In the first instance the machine was operating beside an open window exposed to a blast of sand and grit from the streets and in addition had large angle brushes operating in a trailing position. In the second case, the generator was running in a well-ventilated station, free from any trace of dirt or grit with its bearings in perfect alignment. Excessive brush wear due to abrasion will occur during perfect commutation, but the wear may also be occasioned by glowing, pitting or burning of the brushes during faulty commutation.

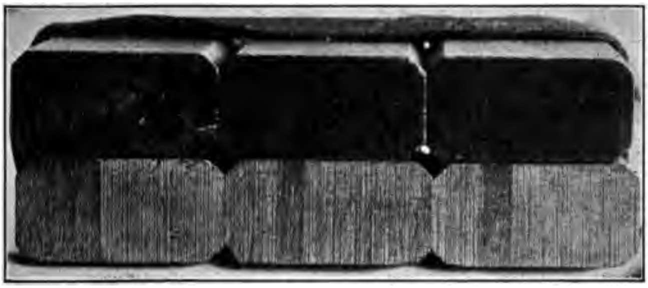


FIG. 88.—Scored brush surface accompanied by poor contact and rapid wear, caused by grit on the commutator surface.

Under good operating conditions, that is, without overloads on the units and freedom from dirt and grit, a set of brushes should ordinarily last from two to three years, with grooved or undercut mica. Where the mica is flush with the commutator surface the life of the brush is from one to two years.

To prevent rapid brush wear, guard against excessive spring pressures and adjust the holders for the proper angle (do not use large angle brushes trailing). Where the machine operates in an atmosphere charged with cement dust or fine iron particles, it is advisable to use a totally enclosed unit and pipe the cooling air from a clean source. It may be necessary to build a separate room for the electrical machinery although usually a protective shield will suffice. Acid or alkali fumes or smoke tend to disintegrate the brushes through a chemical or electrolytic action. Brushes should not be permitted to wear down to such an extent as to permit the metal connections holding the pigtails to cut or score the commutator surface. The length of the standard brush is two and one-half inches and at least one and one-half inches may be worn down before removal, provided the springs are adjustable to permit the proper tension. A rough commutator surface resulting from high or low bars or high mica will also shorten the life of the brushes but one of the greatest causes of rapid brush wear is the sanding or stoning of the commutator while the brushes are down.

GLOWING AND PITTING OF BRUSHES

Symptoms—Glowing.
Under-brush Sparking.
Deterioration of Brushes.

When a brush glows, it becomes red hot and indicates that too much current is flowing in the brush. Glowing is rarely caused by an excessive line current but is due to a current generated by the armature conductors which are short-circuited by the brush. The armature conductors while in a neutral zone may enclose the stray flux from the pole tips and a heavy current will flow through the low resistance made up of the armature conductors short-circuited by the brush. This current added to the line current causes the overload which results in glowing. Glowing may come as a result of selective commutation, where one brush does not take its share of the load on account of poor contacts, poor fit or faulty spring pressure, causing the overloading of the neighboring brushes.

Pitting of the brushes follows directly after glowing. The pitting action eats away the brush, taking place sometimes along the side of the brush where it can be easily seen, but often on the underside of the brush where considerable damage may be done without any visible indications. The pitting or eating away spoils the entire contact surface of the brush by causing the formation of holes, grooves and ridges. These holes vary in depth from one-sixteenth to one-half of an inch, depending upon how long the action has continued. Chattering of the brushes will also cause pitting.

FIG. 89.—Brushes damaged due to pitting, glowing and under brush sparking occasioned by improper adjustment of the commutating field.

Glowing and pitting may be occasioned by the brushes not being in the neutral position bringing about a short-circuiting of armature coils which are still in the influence of the flux from the main pole. The same condition will result from poor design if a brush which is too wide is employed, as this will short-circuit too large a number of commutator bars.

As a check upon faulty design, the heels or toes of the brushes can be filed down one-sixteenth or one-eighth of an inch, and the effect of the thinner brush noted. This, if successful, can be used as a temporary measure until new holders and thinner brushes have been secured. Shifting of the brushes should also be resorted to, to prevent glowing, in order to get a better neutral setting by removing the short-circuited armature coils from the influence from the flux from the main-pole tips. Brushes on machines not equipped with commutating poles will sometimes glow excessively at no load if the shift from the neutral is too great (too far forward in the direction of rotation in the case of a generator and too far backward against the direction of rotation, in the case of a motor).

LOOSE CONNECTIONS—BURNT-OFF PIGTAILS

Symptoms—Sparking.
Selective Commutation.
Glowing Following from Brush to Brush.

A loose connection between the brush and the pigtail while not an especially serious trouble, unless 10 per cent. or more of the brushes are faulty in this particular, will result in poor and selective commutation. Ordinarily when the connection on a single brush is loose, no outward evidences of trouble will appear unless the machine is heavily overloaded, when sparking and glowing at the brushes on the same stud will occur. When 10 per cent. or more of the connections are loose, unless the machine is very lightly loaded, the sparking and glowing will become so serious that it may be necessary to diminish the load or remove the unit from the line. A good diagnosis of this condition, can frequently be made when the sparking and glowing follows from one brush to another across the entire stud or from stud to stud of the same polarity. This symptom can also be noticed when the brushes stick in the holders but it is a pretty sure evidence of poor contacts.

Loose connections result from defective workmanship, poor tinning and soldering, damage incurred in handling, chattering of the brushes or high temperatures occasioned by overloads. When the connection on a brush loosens for any of the above reasons it should be scrapped as no permanent repair can be made without incurring the possibility of unreliability. High temperatures from overload or selective commutation will melt the solder at the connection. The burning off of the pigtails occurs on the brushes on the stud having good contacts for practically all of the load is carried by these brushes when the connection becomes loose on the faulty brush. The severing of the pigtail by the overload current will make the load shift back to the brushes with poor contacts or the current may pass through the boxes and cause glowing and severe heating.

The connections between the brush-holder brackets or bus ring ears are another source of trouble from selective commutation and care must be exercised to keep the bolts at these contacts tightened. The shrinkage of the insulating collars is sufficient to allow a shifting of the connection. The stud attached to the bus ring by a faulty connection will show sparking. Loose connections will upset the electrical balance in the armature circuits and thus all contacts should be kept perfectly tight.

VIBRATION OF THE BRUSH RIGGING

Symptoms—Sparking of the Brushes at All Loads.
Vibration of Rigging Noted by Hand.

Vibration of the brush rigging will produce a general sparking under all of the brushes. The nature of this sparking is very similar to that noticed during chattering inasmuch as it is a mechanical rather than an electrical spark and thus lacks the snappy, bright, burning arc. The vibration may also be detected by placing the hand on the brush holders or brackets when the machine is in operation.

Brush riggings are supported in three ways, namely, by the magnet frame, by the pillow block or directly by the base or foundation. Where the brush rigging is supported by the magnet frame, vibration will usually be due to the failure to tighten the set screws in the magnet yoke which are designed to hold the brush-holder yoke firmly in position. With the pillow-block construction most trouble is experienced as the bearing fit for the supporting yoke must necessarily be small and the overhang of the brush rigging gives a large leverage. Vibration in the yoke is increased by vibration in the bearing pedestals which support the revolving parts. The fit of the yoke on the bearing housing should be tight and the joints between the halves should be so machined as to allow the yoke to be in contact over the entire inside circumference. If the yoke is supported by the set screw used for locking the yoke in place instead of by a perfect fit throughout the circumference, a great deal of vibration will be noted. In such cases, the two halves of the yokes should be disassembled and the joints filed until a good fit is obtained. If this does not entirely suffice to remove the vibration, it may be necessary where the overhang of the brush rigging is eighteen inches or more, to connect together the ends of all of the studs next to the commutator leads by means of tie rings made up of wood, fibre or other insulating materials, and support these rings from the upper or lower half of the magnet frame with a tie piece of non-magnetic material. A roller may be used in connection with the tie piece support where it is necessary to shift the brushes during operation. Vibration of the bearing pedestal should be corrected by tightening of the holding down bolts or wedging up under the base at the points where the vibration is noticeable when the finger tips are placed at the junction of the base and the foundation. When the brush rigging is supported by the base or foundation, vibration is usually caused by loose bolts or a slight movement of the foundation under the brush-holder yoke. If the tightening of the bolts does not remedy the trouble, a tie piece placed between the upper half of the magnet yoke and the upper section of the ring supporting the brush rigging will generally accomplish the result.

Brushes sticking in the holders or eccentricity of the commutator will cause excessive vibration in any of the types of brush rigging supports.

COMMUTATOR TROUBLES AFFECTING COMMUTATION

HIGH MICA—HIGH AND LOW COMMUTATOR BARS—OIL-SOAKED MICA—ROUGH AND GROOVED COMMUTATOR SURFACE—DIRTY SURFACE—SHORT-CIRCUITED SEGMENTS—BROKEN COMMUTATOR BOLTS

HIGH MICA

Symptoms—**Excessive Brush Wear.**
Ring Fire.
Brush Chatter.
Blackening of Commutator Segments.

Side mica, or the mica between the commutator segments, which extends above the commutator surface, will cause sparking at the brushes and the burning and blackening of all of the commutator segments. This sparking is usually accompanied by ring fire, that is, a fine ring of fire encircling the commutator, resulting from the short-circuiting of segments by particles of the brushes worn away by the high mica. Ring fire at first is not serious but gradually growing worse, it may cause the machine to flash over from stud to stud doing serious damage to the commutator and brushes. The blackening of all of the bars, when high mica is present begins at the leaving edge and gradually works across the bar until the entire surface is burnt. High mica is also evidenced by the chatter of the brushes, and usually results from the use of brushes which do not contain sufficient abrasive material to cut the mica at the same rate as the copper.

In the manufacture of a commutator, after assembly it is baked out thoroughly in an oven at high temperatures ranging from 100 degrees to 200 degrees Centigrade to remove all solvent matter from the mica insulation. During this baking process, a commutator should be vented by drilling holes in the clamping rings or spider to permit the easy exit of the gases formed. When this treatment is omitted, the commutator will not be properly seasoned or settled and after a short period of service, unless the clamping bolts are continually tightened, the mica between segments will tend to work out. The vent holes drilled for baking are carefully plugged and sealed when the operation is completed. The commutator bolts should be kept reasonably tightened at all times.

FIG. 90.—Roughened commutator surface caused by high mica. Note that mica has been subsequently grooved to remedy this trouble.

High mica may be temporarily relieved by sanding the commutator surface with fine sandpaper when ring fire or sparking is first noticed, the brushes being raised from the commutator surface during sanding. It can be permanently remedied by slightly grooving or undercutting the mica below the commutator surface. The depth of the grooving will depend upon the thickness of the mica and the volts between segments. The usual thickness employed where the mica is flush with the surface is not less than twenty mils and not more than thirty mils, corresponding to a range in the voltage between segments of from ten to eighteen volts. With these thicknesses of mica it is not safe to undercut more than one-thirty-second of an inch on account of the danger of the collection of dirt and copper particles in the narrow grooves. The grooving however may be extended below this depth providing that the edges of the commutator bars are slightly beveled off to extend the thickness of the groove to at least forty mils. In modern machines, flush mica is very rarely used but instead, the side mica of at least forty mils in thickness is slotted to a depth of one-sixteenth of an inch. This undercutting permits the use of a soft brush without abrasive material which in turn greatly lengthens the life of the commutator and brushes. With a one-sixteenth of an inch slot no trouble is experienced due to accumulations of particles in the grooves on account of the machine "throwing out" and cleaning itself at practically all speeds. A groove more than forty mils wide will cause noisy operation on account of brush chatter.

Fig 91.—Commutator showing high mica and burning of the surface on account of the attendant sparking; also ridges between brushes caused by improper brush stagger.

Commutator mica may be grooved by means of a slotting machine, many of which are on the market and usually consist of a small motor-driven circular saw. Grooving may also be accomplished by the use of a hack-saw blade or a curved three-cornered or riffle file. After grooving, great care should be exercised to see that all of the mica has been undercut to the full depth of the groove and that no small fins remain on either side. Mica fins will gradually work out and cause continuous trouble from faulty commutation and spotting of the commutator surface. A usual method is to remove the fin after grooving by means of a sharp knife or tool.

Fig. 92.—A later view of the commutator shown in Fig. 70 after operating with grooved mica. A perfect surface has been produced, free from roughness, ridges and blackened spots.

HIGH AND LOW COMMUTATOR BARS

Symptoms—Clicking Noise at Low Speeds
Breaking off of Brushes
Sparking at Successive Studs

When a commutator develops a high bar or bars, it is readily noticeable at low speeds, that is, when starting or stopping, by a clicking noise when the high spot touches each set of brushes. This noise is usually accompanied, if the machine is under voltage, by a mechanical spark passing successively around the commutator, that is, successively at each set of brushes. If the machine is operated for any length of time after the high bar has developed, a black spot will appear on the commutator at the point where the high bar is located due to a poor contact or arcing over when the brushes jump from the surface.

A high spot may be due to one or more bars or an entire section of high bars. This is usually due to a soft spot in the cone or ring mica which permits the bar or a section of bars to rise out of place due to centrifugal force. The number of high bars will depend upon the extent of the soft spot in the mica. Sometimes the commutator bolts, holding the rings in place are drawn up to such a tension as to break the bar at the conical seat. Here again just one bar may be broken and caused to extend above the surface or a number of bars under the influence of the bolt may be affected. A breaking of one of the conical seats may be recognized by the fact that one end of the commutator only gives evidence of having high bars. In cases of too much tension on the commutator bolts, especially in long commutators, where the conical seat does not break, the entire central section of the commutator may bow up while the ends remain in place or drop slightly. The excessive centrifugal force produced when the machine overspeeds may also cause high bars. Where the conical seat is broken it is necessary to rebuild the commutator but it is possible in the case of soft mica, to remove the clamping ring and shim up the soft spot with thin sheets of mica. The ring is then replaced and tightened and the commutator surface turned or ground and smoothed. When the tension on the commutator bolts is too great, producing a bowing up of the central section, it is possible where the elastic limit of the copper has not been exceeded, to relieve the excessive tension on the bolts and true up the commutator surface by grinding or turning.

Low commutator bars present a real serious trouble and one which is difficult to remedy save by the complete rebuilding of the commutator. Low bars are discernible in practically the same ways as high bars, namely by the clicking noise produced at low speeds and the blackening of the commutator surface at the low section. It is only infrequently that just one bar will fall below the surface but usually an entire section will be affected. When the commutator is assembled, the segments and side mica are arranged to form an arch and held in place by an external ring or rings. After machining, the spider and clamping ring are assembled to support the arch from the inside. In the advent of rough handling such as dropping or striking, the arch is broken and while it may be possible in a few instances to restore the surface by grinding and turning, it is usually necessary to restore the arch by rebuilding the entire commutator. In case the arch is not broken over the entire length of the commutator, but simply low at either end, it is possible to remove the clamping ring and increase the thickness of the mica by the insertion of thin sheets under the low points. This in many cases, however, results in loose side mica on the affected end.

OIL-SOAKED MICA

Symptoms—Ring Fire.
Honeycombing of Mica.
Grounds.

If the mica insulation on a commutator becomes oil soaked, it will be necessary in a short while to rebuild the commutator and furnish new mica throughout. For this reason it is imperative that all possibilities of oil being thrown upon the commutator be removed. Sources of this danger are very common, such as leaky bearings which permit oil to creep along the shaft and enter the spider and rings of the commutator, revolving parts of engines such as cranks or eccentrics being improperly or insufficiently guarded or operation in an oily atmosphere particularly around gas engines. Frequent use of a lubricant on the commutator is also a very common cause of this trouble.

When the side mica becomes oil soaked, arcing between the commutator segments accompanied by ring fire will ensue. An examination of the side mica will reveal a honeycombed condition with carbonized paths which may be eaten to considerable depths, sometimes from two to three inches, and a blackened condition between the affected bars. When these paths are burnt through to the cone or bed mica, a ground results and serious burning will necessitate the removal of the unit from service for repair. If the trouble is noticed at its beginning, that is, before the carbonized path has reached an appreciable depth of not over one-half an inch, it is possible to make temporary repairs by cutting away all of the carbonized mica and removing all burnt particles, after which the slot is filled with a commutator compound sold by manufacturers of electrical apparatus for this purpose. Under emergency conditions and where it is impossible to secure a special commutator compound already prepared, a paste made of water glass and plaster-of-Paris may be applied after the burned particles have been thoroughly scraped out. Commutators treated in this way have been known to give satisfactory service for long periods of time but as a general rule it is necessary in the end to rebuild the commutator and furnish new mica throughout.

A test for oil-soaked mica is to place a sample strip in a vise and when pressure has been exerted, noting if oil appears at the edges. When oil creeps along the shaft and enters the cone mica through the opening between the clamp ring and the spider, a complete replacement of the mica may be unnecessary and generally the above test will show that a replacement of the cone mica alone will suffice. Instead of using lubricating oil for removing smut on the commutator surface, wiping with waste dipped in kerosene, gasoline or alcohol is recommended in order to eliminate the danger of introducing oil into the mica. It should be remembered, however, that the above solvents are highly inflammable and will explode when applied to a hot commutator surface where there is any sparking at the brushes. For this reason, the voltage should not be on the machine while cleaning.

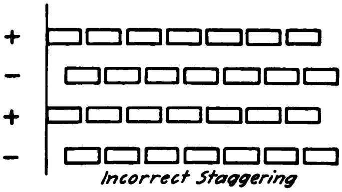
ROUGH AND GROOVED COMMUTATOR SURFACE

Symptoms—Sparking.
Chatter.
Burning.
Formation of Grooves.

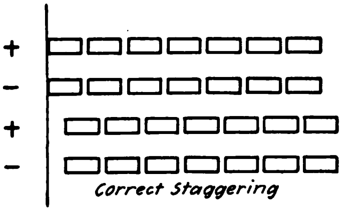
A rough commutator surface may present a deceiving illusion while the machine is standing still, as the commutator may appear to be relatively smooth and in good condition. When in operation, however, its uneven surface will be evidenced by sparking at the brushes, chatter and in some cases vibration of the entire unit. The causes for a rough commutator surface are high or low bars, high mica, improper commutator seasoning, metal beads on the surface formed by flashovers, burns from short-circuits, bowing up or deformation due to high temperatures, eccentricity due to the flexure of the shaft and the failure to turn or grind at the proper speed, that is 300 feet per minute for turning and 1800 feet per minute for grinding, or taking too large a cut in the turning or grinding. When the surface of the commutator has become rough for any of the above reasons, it may in mild cases, be possible to restore it to its original condition by the use of fine sandpaper applied by hand, with a block of wood fitted to the commutator surface (the brushes of course being lifted during this operation). Where the use of sandpaper will not produce the desired results, a commutator sandstone may be applied by hand but in no cases should carborundum or emery be employed, since fine particles of these hard substances will become imbedded in the brushes and cause sparking, commutator wear and short-circuits between bars. If the commutator is appreciably eccentric, it is practically always necessary to turn or grind it and finish with fine sandpaper before satisfactory results will be secured. During the process of sandpapering or sandstoning by hand, the copper dust should be collected and thus prevented from entering the windings of the machine by means of holding a piece of waste just in front of the sandpaper or stone in the direction of rotation. Even when this precaution is taken, the machine should be carefully blown out before voltage is applied. The turning and grinding of a commutator is taken up in detail on Page 69 of Chapter IV.

FIG. 93.—Scored commutator surface resulting from exposure of the machine to a blast of concrete dust. Note also the scoring on the brush faces.

Grooving or cutting of the commutator surface will in general not cause sparking when the grooving is due to brush wear or grit on the surface, or to electrolytic action between the brush and the bar. If the revolving element of the machine is permitted to float freely in the bearings as in the case of belted machines or motor generator sets, the cutting action will be distributed over the entire surface. When the revolving element is fixed in regard to horizontal movement such as in the case of direct-connected, engine-driven generators or motors connected to pumps or gears, the grooving or cutting will be very noticeable. Proper staggering of the brushes will eliminate this trouble but it should be noted that it is necessary to so stagger the brushes as to prevent brushes of the same polarity from tracking each other as the electrolytic action where the current passes from carbon to copper or from copper to carbon will gradually eat away the bars and accelerate the grooving. Brushes should be staggered in pairs of studs allowing a positive brush to follow the same path as the negative brush to offset the electrolytic effect. The positive and negative brushes should be so distributed over the surface as to wear all parts of the surface uniformly. In a 4- or 8- pole machine, it is possible to stagger the brushes in pairs of studs. With a 6-pole machine however it is necessary to stagger four of the six studs in pairs and break joints



Incorrect Staggering



Correct Staggering

FIG. 94.—A sketch showing the correct and incorrect stagger of the brushes.

with the remaining two studs. On generators used in electrolytic work, where the ampere load runs into thousands over long periods, it is advisable in addition to the staggering of the brushes, to furnish a mechanical or electrical oscillating device to prevent grooving.

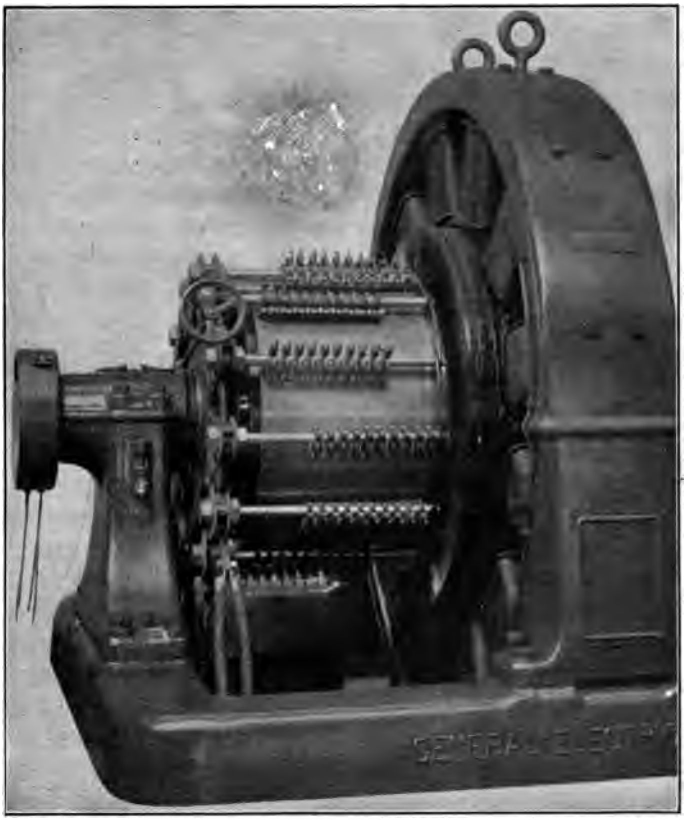


Fig. 95.—A view of a commutator showing the correct staggering of brushes in pairs. (The additional length of the commutator is not found in practice but is used above to illustrate only.)

The proper staggering of the brushes on the commutator is shown in Figures 94 and 95.

DIRTY SURFACE

Symptoms—Sparking
Glowing.
Fluctuation in Voltage or Failure to Start.

A dirty commutator surface very frequently results from the use of a lubricant on the commutator or the fitting of brushes containing lubricant which will exude when the brush becomes heated. A graphite brush will produce a smut upon the commutator surface if the machine is operating in an oil-charged atmosphere on account of the mixing of the graphite with the oil. In the advent of flashing over on a machine, the commutator surface will become covered with burnt particles of insulation, copper mica and carbon.

When the commutator becomes dirty from any of these causes and especially where a lubricant is used, the collection of dirt and lint upon the surface will work up under the brushes or between the brushes and the brush holders preventing the proper free movement. This produces sparking on account of the poor electrical contact and will be accompanied by heating of the brushes. In a generator, a very dirty commutator may cause the machine to fail to pick up or if running, to drop, in voltage appreciably. In a motor, a decrease in speed will be noticed as well as sparking at the commutator. In fractional horse-power motors, such as those installed on washing machines or electric fans, where the spring pressure on the brushes is very light, the motor will fail to start until the commutator surface is clean.

Avoid the use of all lubricant on the commutator and guard against the fitting of brushes which contain an excessive amount of lubricant, which will exude upon heating. The commutator surface should be cleaned with fine sandpaper with the brushes up and each brush should be carefully wiped off with waste. If a coat of smut alone exists no sandpaper will be required, as a slight amount of kerosene, gasoline or alcohol applied with a rag (with the brushes raised) will usually suffice.

Acids or alkali fumes, practically all of which have a very corrosive action upon copper, will coat the entire surface of the commutator with a film of a non-conducting material, resulting in sparking and rapid wear of the commutator and brushes. This action is particularly noticeable where the unit is not operated continuously but will also take place where the commutator is always in motion. Cleaning continuously

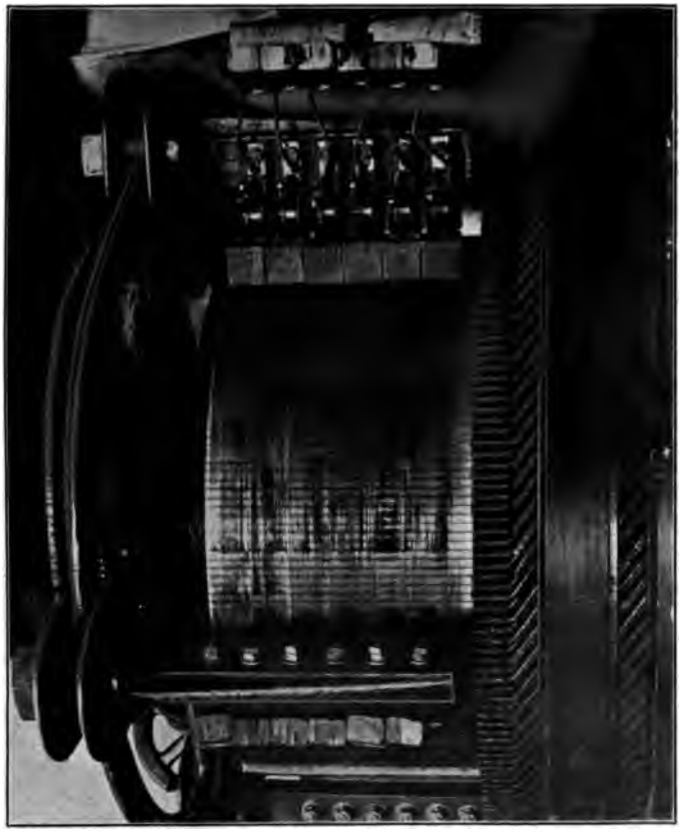


FIG. 96.—Dirty commutator surface caused by the use of a lubricant on the commutator in connection with graphite brushes. Note the collection of smut on the faces of the exposed brushes.

with canvas or porous cloths will reduce the sparking to a minimum but the only permanent remedy is to completely enclose the machine either with end shields or a separate compartment and then furnish clean cooling air. Where it is not possible to remove the unit from such local conditions, both carbon and graphite brushes are used; the carbon brushes supply the necessary abrasive to cut through the insulating film while the graphite brushes afford sufficient lubrication.

Flashing at the commutator, burning or grounding can be oftentimes traced to the failure to properly clean the creepage surfaces, at the ends of the segments where the clamping rings and the copper come very close together. This creepage surface varies in length from one-half inch in one hundred twenty-five volt machines to three to four inches where voltages of fifteen hundred to two thousand are obtained. The creepage surface is made by placing an insulating collar of mica around the clamping ring, held in place by cord, which in varnished, shellaced or painted. If collections of copper, carbon dust, water or grease are permitted to remain upon this surface, a low-resistance path from the copper bars to the ground is formed and the machine will be grounded. Burning and flashing will take place, destroying the insulation on the

FIG. 97.—Coated brush surface caused by collection of dirt on commutator.

clamping rings. Particular attention should be paid to the creepage surface when the machine is being cleaned after grinding, turning or sandpapering. It is customary to extend the creepage surface by insulating completely around the end of the clamping ring as well as the outside circumference on machines used in mining service or where exposed to moisture.

SHORT-CIRCUITED SEGMENTS

Symptoms—Ring Fire.
Heating and Burning.
Fluctuation of Voltage.

Short-circuited segments may be due to a blow forcing two segments to come into contact, or to copper bridges forming between bars during turning or grinding, particularly where the mica is undercut. Solder running from overheated brushes, dropping of burnt-off pigtails and the collection of current carrying foreign matter in the slots are also causes of this trouble. If the short-circuit produces a contact of comparatively high resistance, heating and burning at the point of short-circuit is usually noticed and a ring of fire around the commutator over this point will be observed. If the contact at the short-circuit has a low resistance, a variation in voltage on the voltmeter will show accompanied by a flicker in the lights in the case of a generator. Unless the machine is immediately shut down (it is not sufficient to remove the field only as the residual magnetism will be sufficient to continue the action) the entire armature coil will be burned out due to the heavy flow of current. After shutting down, the machine should be thoroughly examined and the short-circuiting condition remedied. It is usually easy to find the coil short-circuited by two segments in contact by placing the hand on the surface of the armature windings or the soldered clips on the front or back ends and detecting those which have the highest temperature. The solder on the end clips will melt and run before the armature insulation fails although considerable smoke may be in evidence. If the commutator segments blacken in service after being subjected to the short-circuit, the clips should be resoldered and the joints made sound. Oftentimes the incorrect supposition is made in this latter case, that the commutator bars become softened due to annealing during the short-circuit. Short-circuits also occur between the commutator leads or risers producing the same effects as just described.

FIG. 98.—Commutator having a burned surface as a result of severe short circuits while not in operation. Note also the condition of the surface preceding the formation of ridges due to lack of brush stagger.

BROKEN COMMUTATOR BOLTS

Symptoms—Flying Bolts.
Loosened Commutator Segments.

Broken commutator bolts are a somewhat infrequent cause of trouble but may present a serious danger to the safety of the operator and the operation of the machine. When the defect is first noticed by the breaking of the first bolt, the unit should be immediately removed from service and permanent repairs made. The fracture of the bolt is caused by the expansion of the commutator segments due to high temperatures or in some cases, to an unequal distribution of the tension in the commutator resulting in an overstressing of one of the bolts. Where comparatively short bolts are employed for holding the clamping rings instead of long through bolts, the unequal expansions of the short bolts and the longer copper segments produces the excessive tension. Replacing the short bolts with bolts of the same length but a higher tensile strength will not effect the anticipated remedy as the conical seat of the segments will break or the central section of the commutator will bow up if the bolts hold. A short bolt usually extends through the ring and into the spider approximately one and one-half diameters. Bolts of a sufficient length to permit of considerable expansion should be substituted in this case. The drilling for the short bolt in the commutator spider should be continued until a depth is reached which permits the use of a bolt from two and one-half to three times the length of the original bolt. The new bolt should be "necked down" just above the threads for a distance equal to at least two diameters. The reduction in diameter or "necking down" should not bring the size of the bolt below the dimension at the bottom of the thread. Both ends of the commutator should be given this treatment even though the trouble may have developed on one end only. In case it is mechanically possible to drill the spider the entire length and use long through bolts, to hold both front and back clamping rings, it is advisable to adopt this arrangement. The through bolts should be reduced in diameter in the center over a space of from three to four diameters as mentioned above. Commutators constructed with through bolts instead of short bolts, give best results and in case such a bolt breaks it is due to unequal strains produced when the commutator is assembled, and a new bolt may be inserted without renewing the remaining bolts although an examination of their condition is advised. A commutator should not be operated with one or more of its bolts defective whether of the long- or short-bolt type. Clamping rings are frequently strained out of shape by excess tightening and when making an examination for defective bolts it is well to remove the clamping ring and test its surfaces with a straight edge. Unless the clamping ring has been stressed far beyond its elastic limit, it can be readily pulled back into shape. Steel chips produced by a breaking bolt may cause a ground and care should be taken to see that all fragments are removed particularly after a ring has been taken out for examination.

COMMUTATION TROUBLES FROM OTHER CAUSES

WEAK FIELD—OPEN CIRCUIT IN THE ARMATURE—GROUNDS —OVERLOADS AND VARIABLE LOADS—POORLY BALANCED ARMATURE—FAULTY DESIGN

WEAK FIELD

Symptoms—Sparking.
Variable Voltage or Speed.

Faulty commutation will come as a result of a weak field, along with poor voltage regulation in the case of a generator and poor speed regulation on a motor. Where a machine not equipped with commutating poles, is designed to have a high armature reaction (that is, with a great number of armature conductors), as compared with the main field flux, sparking and instability of voltage or speed will occur if the machine is operated above its normal rating in amperage. This condition is due to the improper relation between the field strength and the armature reaction and results when the magnetism developed by the armature current becomes relatively strong and shifts the point of minimum sparking, that is, the neutral, from its normal position. As the brushes remain stationary, sparking results. Commutation may be improved by increasing the main field air gap, where shims or liners are provided for adjustment on machines not equipped with commutating poles. The increased air gap makes it possible to operate with less shifting of the brushes and the cross magnetization in the armature is reduced as a result. With machines fitted with commutating poles, properly adjusted, little or no trouble is experienced from weak main fields, since the armature reaction is compensated for by the commutating field.

A machine poorly designed, that is, with a very high armature reaction as compared with its field flux may be made to operate successfully at its normal ampere and voltage rating but will commutate unsatisfactorily when any appreciable change is made in the load conditions, that is, when the amperage is increased with constant rated voltage or a decrease in the voltage at constant rated amperage occurs. In ordinary cases, the weakness of the field may be caused by too small a field current resulting from too much resistance in the field circuit, poor contacts or high temperatures of the field coils. A reversed connection of one or more field coils causing it to oppose the others or an improper connection of the series field on a compound-wound motor or generator with respect to the shunt coils will also cause a weakened field. If the series coils are improperly connected with respect to the shunt field on a compound-wound generator, the series field will lower the voltage with an increase of load instead of raising it while on a compound-wound motor, it will cause an increase in speed due to a weakening of the field.

The improper connection of the individual field coils with respect to each other may be detected by holding a compass needle near the poles while the field current is passing through the coils. Adjacent poles should attract opposite ends of the needle. A weak field caused by an improper connection of the individual coils requires only the reversal of the connecting leads. The proper or improper connections of the series coils on a compound-wound generator or motor with respect to the shunt coils may be determined by noting if the current passes through both sets in the same direction which it should do in order to produce the proper results. When the low field current is due to too much resistance in the field circuit, cutting out resistance in the field rheostat should of course be resorted to.

Motors operating under a weakened field condition, spark at the commutator on account of overloads as well as the shifting of the neutral point as mentioned above, where the mechanical load is great enough to prevent the increase in speed of the armature corresponding to the weakened field condition. The counter-electromotive force can only be increased where the field value is fixed by an increase in speed, prevented in this case by the mechanical load. It should be remembered that the current in the motor armature is limited by the counter-electromotive force and also by the resistance of the winding, brushes and connections. This resistance is fixed and unless the speed can change with a variable field current, over-loading will result.

OPEN CIRCUIT IN THE ARMATURE

Symptoms—Flashing at Successive Studs.
Blackened Bar.
Failure to Start in Case of Motor.
Variation in Voltage in Generator.

An open circuit in an armature winding always results in the blackening and burning of the commutator segment connected to the open-circuited conductor. The entire set of brushes on each stud will flash and spark successively around the machine as the bar connected to the defective circuit passes under it. The flashing is not similar to the usual spark noticed at the commutator due to other causes but is violent, snappy and very destructive. On a generator, a variation in the voltage accompanied by a flicker in the lights will be noted. In a motor, if the circuit has been broken before the original starting, it will refuse to start unless one set of brushes happens to be in the proper position to close the circuit. If, however, the motor gets up to speed or the circuit is broken during operation, the motor will continue to run providing the mechanical load is light. The speed regulation will be unsteady and the rotary motion, when the motor is relatively well loaded, will be jerky.

The open circuit may be caused by a breaking of the commutator leads or risers due to vibration or movement between the commutator and the armature core. These connections may be opened by the removal of the solder due to high temperatures occasioned by overloads or by faulty contacts. Where the armature is wound with fine wire, as is the case with small machines, no commutator leads or risers are used, and the open circuit usually is found where the wire conductor is soldered to the commutator segment. Wire-wound armatures may be open circuited by burning due to short-circuits between adjacent conductors. Rough handling is a frequent cause of broken connections.

All conductors in an armature winding are connected in a closed circuit through the commutator segments. When one conductor is opened the commutator segment to which it is connected is removed from the continuous circuit and as this segment passes in succession under each set of brushes, it is bridged by the brushes and the circuit is closed and current builds up. The breaking of this circuit will produce a violent flashing due to the inertia of the current which has built up.

Upon noticing the above symptoms, the machine should be immediately removed from service. If a commutator lead or riser is found to be broken, a copper sleeve may be made from a thin sheet of copper and soldered around the broken points of the lead to make a firm joint. If an end clip has thrown its solder, due to overheating, it should be securely resoldered. A coil open circuited in the core or slot due to burning must be replaced or a soldered repair made where mechanically possible. Replacing an armature coil is described on Page 242. Temporary repairs for emergency conditions may be made in case of an open circuit by connecting together the two commutator segments adjoining the defective bar and the defective segment with a copper stud firmly soldered into position. This connection may also be made by pounding the copper segments at the ends to make a contact between the bars thus forming a closed circuit or by soldering a strip on the commutator leads or end clips on the armature winding. In high-speed machines, where it is difficult to solder connecting strips securely enough to stand the centrifugal strain, the repair is sometimes effected by drilling and tapping between the two adjoining segments and the defective bar and introducing a short screw between each bar. This practice, however, is not recommended as it is apt to destroy the mica insulation and cause trouble in the future. It is also possible to bridge over the open segment by throwing the brush holder studs slightly out of line so as to span one or more commutator segments than are covered when in the normal position. This represents, however, a very temporary makeshift as a further trouble would be incurred due to the misalignment of the studs. If the open circuit occurs in the coil, it is necessary to either repair the coil or bridge the commutator segment connected to the coil. It is not necessary to do both and usually the latter procedure will be the easier. Where a connection is made in such a way as to close the armature circuit by cutting out the open-circuited coil, that is, by using a jumper, the commutator segments must also be bridged.

GROUNDS

Symptoms — Sparking.
High Temperatures.

When a machine which has been operating satisfactorily for some time, suddenly develops commutation trouble which cannot be traced directly to any defective condition of the brushes, commutator or connections, particularly if the unit has been operating on a grounded circuit such as is common in railway or marine practice, it should be shut down at once and an examination made for a second ground. This second ground will cause sparking by overloading the unit in the same manner as a short-circuit in the armature. One ground in the armature will not produce trouble because there is no return circuit or complete path for the current. The second ground provides this path and develops the sparking due to the attendant overloading. The sparking from grounds occurs at all brushes and studs and is usually accompanied by glowing and heating of the brushes. If the ground is of low resistance, the sparkling will continue even after the external circuit is opened and in most instances the residual magnetism in the main poles is sufficient to cause a large enough circulation of current to continue the sparking.

A ground in the armature is usually caused by a failure of the insulation in the slot between the conductor and the core or between the conductors and the flanges. It may also be due to a breaking down of the mica in the commutator or the failure to keep creepage surfaces or dirt pockets in the end windings, ventilating ducts or flange rings free from accumulations of copper, carbon dust or other current-carrying materials. When an armature is exposed to flying metal chips from lathes or other machine tools, grounds may appear when these particles happen to fall into positions so that they connect the live parts of the machine to the ground. The usual places where these chips cause trouble are in the end windings, soldered clips, ventilating air ducts or just in back of the commutator leads. After rewinding or initial assembly, the machine may develop a ground, due to metal particles, which have been permitted to remain under the windings or in the slots, chafing through the coil insulation on account of the slight movement of the coil in service. If an armature core becomes loose on its dovetails or between its flanges or if the space blocks in the ventilating air ducts become loosened and work out, the punchings will shift due to centrifugal force and result in cutting through the insulation on the conductors usually at the ends of the core or at the air ducts, producing serious grounds. If the binding bands over the end windings or core portions become loose due to the shrinkage of the insulation or to overspeed, or if the retaining wedges in the core portion shrink as a result of high temperatures or improper seasoning and permit of movement of the conductors in the slots or on the end flanges, grounds will shortly appear due to chafing or rubbing of the insulation. Grounds are also caused by the application of high potential tests before all accumulations have been carefully removed from all parts of the machine and especially the end windings. Before high potential tests are applied all machines should be thoroughly cleaned by carefully wiping and blowing out and where the unit has been running or standing under moist conditions a complete drying out should be effected by baking.

Sometimes a high resistance ground is first detected by the operator coming in contact with live parts of the circuit on either the positive or negative side and receiving a shock when the unit is operating on a system which is not intentionally grounded. The extent of the ground should be determined with a voltmeter by measuring the drop and insulation resistance from the live circuit to the ground, as described on Page 219, and if the insulation resistance is found to be under 500,000 ohms, it is necessary to remove the machine from service and make repairs. An indicated resistance of above 500,000 ohms will insure safe operating conditions. A magneto fitted with a bell connected between the live circuit and the ground preferably between the commutator and the shaft will indicate a ground by the ringing of the bell. Where it is difficult to locate the definite point of ground, a voltage, preferably alternating current, should be applied between the commutator and shaft with a resistance in the circuit to limit the flow of current, and continued until smoke appears at the grounded point.

After the point of ground has been located, the repair of course will depend upon the condition found. If the trouble is due to chips or metal particles, they should be removed and the damaged insulation repaired as described on Page 247. A ground resulting from moisture or collections of dirt or current-carrying material can be easily removed by thorough cleaning unless the insulation has been impaired. Armature coils, grounded in the slot portions or end windings as a result of loose laminations or space blocks, chafing or rough handling, usually require replacement of the damaged coils. Flashing over to the ground due to short-circuits or sudden swings of load results in the formation of a carbonized path from the live circuit to the ground and such paths should be given a coat of insulating varnish after all of the carbonized material has been completely removed. Where a ground is due to loose laminations cutting through the coil insulation, it is useless to attempt to rewind the armature until effective repairs have been made upon the core, as given on Page 195.

OVERLOADS AND VARIABLE LOADS

Symptoms—Sparking.
High Temperatures.

Overloading a machine beyond its rated capacity results in sparking, accompanied by heating and glowing of the brushes due to the excessive current which they are carrying. A machine sparks when overloaded because of the high current density in the brushes, high maximum volts between segments due to a change in the wave shape of the voltage curve, high armature reaction causing a shifting of the neutral point, improper adjustment of the fields caused by the overheating of adjusting shunts and unbalanced circuits in the armature winding. The sparking is of such a nature as to damage both the brushes and the commutator, whose surface will be burned and discolored due to heating especially if the overload is allowed to continue over too long a period. The manufacturer's guarantee is stamped on the nameplate on modern machines and the conditions outlined should not be exceeded. When the normal load is exceeded for short periods, commutation is usually the limiting feature. Unless the overload exceeds 25 per cent. for more than two hours on machines up to three hundred kilowatts with voltages up to two hundred fifty, no permanent damage should result. The momentary overload for such machines is from 50 to 75 per cent. Above 250 volts, the usual two hour overload guarantee is 50 per cent. with a possible momentary overload of 100 per cent. Machines which are maximum rated are designed to operate with a high brush density and no overload is provided for, such machines will be seriously damaged by the overheating of the brushes and the commutator as well as the windings, if an overload is allowed to exist.

Sparking results from a variable load because of the continuous shifting of the neutral point in machines not equipped with commutating poles. Sparking on a machine designed with commutating poles is due to the failure of the current to pass through the commutating fields which are inductive as compared with the shunt across the commutating field which is practically non-inductive except in special cases. Swings in the load current will pass through the non-inductive circuit and sparking results because the armature reaction is not compensated for by the commutating pole as the current does not pass through the commutating pole windings at the time of the swing. Machines designed for service where the load is very unsteady such as railways, hoists and elevators should have no shunt across the commutating field unless the shunt is made of the inductive type to force the current through the commutating fields at all times. If, however, the commutating windings are proportioned so as to require very little shunting, the ohmic resistance of the small shunt necessary is nearly always sufficient to cause current enough to pass through the windings even on the swings to make commutation successful. A variable load may also cause variation in the speed of the prime mover and the surging or hunting under such conditions may cause sparking unless the machine has a very wide neutral and a large margin in commutation constants. A sudden application of the load will cause a drop in speed and voltage and in case the unit is running in multiple with other machines, there may be a tendency to motor and flash at the commutator but this is unusual and the equalizer bus will practically always prevent serious trouble. A commutating-pole machine operating on a highly fluctuating load may be materially improved in regard to commutation if the non-inductive shunt is entirely removed from the fields but this requires that the air gap between the commutating pole and the armature be increased to prevent overcompensation for the armature reaction. Frequently, however, this increase of the air gap upsets the proper relation between the slot pitch and the thickness of the commutating-pole tip resulting in faulty commutation. For this reason, it is advisable to shift the brushes forward in the direction of rotation when the shunt is removed rather than change the air gap unless the operator is experienced in making such adjustments. The forward shifting of the brushes requires a stronger field than is required when the brushes are directly on the neutral point for the reason that the conductors under commutation are operating in the fringing of the flux from the commutating poles. To avoid trouble, with voltage regulation and parallel operation, it should be remembered that the forward shift will make it necessary to strengthen the series field to hold the voltage at the value obtained before the shifting of the brushes.

POORLY BALANCED ARMATURE

Symptoms—Mechanical Sparking.
Vibration of Supporting Bearings.

An armature should be in perfect electrical and mechanical balance. The electrical balance, that is, the equalizing of the resistances of the conductor paths so as to cause equal currents to flow in all parts of the armature is effected in multiple-wound armatures by the use of equalizers, which consist of copper conductors connecting all points of equal potential. They are usually placed on the back end of the armature but may be located on the front end just back of and connected to the commutator risers or leads. No equalizers are used on series-wound armatures since each conductor passes under all of the poles in succession before it is connected to the next conductor at the commutator segments and the coil is therefore electrically balanced within itself. To insure against electrical unbalancing, even though the armature is equipped with equalizers, care should be exercised to see that all air gaps are made uniform by means of the liners or shims provided under the pole pieces. Unbalanced armature circuits come as a result of unequal brush spacing, loose connections and unequal spring pressure on all brushes, the effects of and remedies for which have been discussed in previous articles.

So important is the mechanical balance of an armature that manufacturers give each part, such as the commutator, armature spider, and assembled core, with and without windings, a separate static balance and after all assembly and winding, including the final dipping or spraying of the insulating compound and finishing of the commutator has been completed, a very accurate static and dynamic balance is given. A poorly balanced armature will cause vibration resulting in sparking at the brushes and increased wear of the bearings. The sparking is of a mechanical nature, existing at all loads and doing no particular harm to the brushes or commutator, and is lacking in the snap of the electrical spark. All brushes may spark at the same time or they may spark successively around the commutator. An intermittent vibration may be set up in the brush rigging so that the brushes will alternately vibrate and settle down. The unbalancing may be caused by careless workmanship in the factory but frequently the failure to bring both halves of the coupling into perfect alignment, in the case of engine-driven or motor-generator sets, will upset the entire balance. This will also occur if the faces of the half couplings are not perfectly true or if burrs or ridges prevent a perfect joint. A sprung shaft, damaged in shipment or handling will also cause this trouble. When armatures are rewound in service, careful attention should be given to the proper location of binding bands, clips and soldered spots, particularly in smaller machines as some manufacturers depend upon these features for their final balance An infrequent but serious cause of unbalancing is due to some of the brushes sticking in the holders instead of moving freely with the commutator.

The remedies for the above causes of mechanical unbalancing are obvious and all points mentioned should be checked, particularly the shaft for springing. This may be done with a shaft indicator or by means of a piece of chalk held firmly in position so that it will just touch the high side of the shaft in case it runs out of true. If all tests indicate that the armature was poorly balanced when shipped from the factory, weights must be added by drilling and tapping in screws in the armature spider arms or end flanges as far from the shaft axis as possible so as to reduce the size of the weight to a minimum The location of these weights must be determined by experiment or cut and try methods if the armature is to be balanced in its own bearings. The use of a piece of chalk held rigidly against a pole piece in such a position that the high side of the armature core will just touch at each revolution, will give a starting point for adding the balancing weight which, of course, should be placed diametrically opposite to the center of the chalk mark.

Pockets for receiving lead balancers are provided on the inside circumference of armature flanges in most machines.

Where it is necessary to add a very substantial weight this weight should be divided into two parts placed one at each end of the armature.

FAULTY DESIGN

Poorly designed motors and generators never give real satisfaction, because they possess inherent faults which limit the operation to such an extent as to practically remove all flexibility and adaptability to different ranges of service. A well-designed machine offers a generous leeway in heating, commutation, voltage and speed regulation and thereby greatly increases its sphere of usefulness. The most common faults in design which affect the successful commutation of the machine are too much voltage between segments, too great an armature reaction with a low main field flux, high brush density, too few equalizers, insufficient air gap, excessive commutator speed and improperly located connection strips. In a great many cases, troubles attributed to faulty design are directly traceable to incorrect application and a study of the local conditions surrounding the installation and of the fitness of the machine to meet the demands of the service should be made.

The permissible voltage between segments depends upon the type of machine and the requirements of the service. Machines designed for constant loads will operate successfully with a voltage between segments as high as twenty volts while a machine operating on a highly fluctuating load should be designed with an average voltage between segments not to exceed fifteen volts. These values refer to machines equipped with commutating poles as units without commutating poles should have the values reduced 25 to 50 per cent. Generators even though designed with commutating poles, operating in locations where exposed to moisture or collections of dirt, should likewise be considered under this latter class and should carry the reduced voltage between segments. While it is desirable to have a low voltage between segments, it is not always practical since an increased number of commutator segments always results in a corresponding increase of armature conductors, and thus builds up a high armature reaction. Low voltages between segments insures against flashing over under heavy swings of load or short-circuits while high voltages per bar make a machine subject to flashes at the commutator, causing a burning of the brushes and the commutator surface when the current passes between studs of opposite polarity. Volts between segments may be calculated by dividing the line voltage by the number of segments between the center of negative and positive brushes, or by multiplying the line voltage by the number of poles and dividing by the total number of commutator segments. On machines not designed with commutating poles where the main field temperatures are low enough to permit an increase in the main field gap, shims or liners between the main field pole and the frame should be removed. This increase in air gap will in a measure reduce the shifting of the main field flux on the pole faces and as a result the shift of the brushes from their neutral point may be reduced, thus cutting down the cross magnetization of the armature conductors, which lowers in turn the maximum peak or voltage between segments usually found near the trailing pole tips. With a machine equipped with commutating poles, there is no remedy when the voltage between segments is too high, save rebuilding the armature.

When a machine is designed with an armature reaction, exceeding 10,000 ampere turns per pole and a very low main field flux in comparison, such as in machines constructed for electrolytic work, the main field air gap should be made as large as possible by the removal of shims in order to reduce the attendant sparking and instability, when it is desired to operate at a voltage below the normal rating and at the same time maintain the rated armature current. The sparking is occasioned in this case by an interaction between the armature reaction and the main field flux as described in the preceding paragraph. The allowable brush densities for successful commutation have already been given on Page 132. If it should be desired to operate a machine for a greater output and stay within the limits of the current-carrying capacities of the brushes, another brush may be added to each stud if the length of the commutator permits or a wider brush may be substituted, provided that the design of the unit is such as to permit the change. Heating and commutation should be considered as the limiting features in the event of increasing the output of the machine. It is advisable to consult the manufacturer when such changes are contemplated unless the operator is familiar with the design.

Modern armatures of the multiple wound type are equipped with at least one equalizer tap for each slot, which results in an evenly balanced armature and more satisfactory commutation than if the armature had no or too few equalizers. These equalizers are copper connections of low resistance, connecting together all points of equal potential in the armature winding. For example, the armature conductors exactly under the center of all poles of like polarity are joined together since the relation of all of these conductors with respect to the fields is not changed throughout the revolution of the armature. After the first connection has been made a complete set of equalizers may be correctly installed by simply progressing around the armature. Equalizers may be connected either at the back end of the armature or directly to the commutator segments on the front end.

The lack of equalizers or an insufficient number of them will produce blackened segments on the commutator, usually unevenly spaced on the surface and caused by an excessive flow of current through the brushes and bus rings where the unbalancing in the armature circuits is an appreciable amount. The blackened segments may also appear where the armature is fully equalized and in the advent of such a condition, soldered connections either on the equalizers and clips or commutator risers should be examined, as it will be found that the blackening is practically always due to a loose or poor connection. The heavy exchanges of current through the various armature paths, where the machine has no or too few equalizers, will result in the eventual annealing of the commutator segment accompanied by sparking and the formation of low and flat spots on the commutator. To determine whether or not trouble is being experienced because of too few equalizers, first examine all soldered connections on the armature and insure their tightness. Then remove the blackened spots on the commutator with fine sandpaper and prick punch the affected segments. Upon again placing the machine in service, it should be noted whether or not the same bars blacken again. In the advent of the reappearance of the blackening at the same points, the machine should be fitted with additional equalizers, preferably with a sufficient number to provide a tap for each slot. When an armature is wound with more than two bars per slot and each bar is connected to a commutator segment, one equalizer connection per slot may not be sufficient, in which case it is good practice to connect an equalizer tap to every other end clip. Where the armature bars are so connected by end clips as to make up an armature coil consisting of more than one turn, one equalizer tap per coil is sufficient.

The actual addition and placing of the equalizers on the armature is described on page 248.

Insufficient air gap will cause sparking at all of the brushes on machines designed without commutating poles by permitting the shifting of the neutral, due to cross magnetization of the armature conductors. If the air gap is very small on a commutating pole unit, sparking will result from the local magnetic circuit because two or more armature teeth are being practically closed by the commutating pole tip. Shifting of the neutral in this case is prevented by the commutating pole and very small main gaps may be employed as compared with those on non-commutating pole types. However, it should also be remembered that the use of very small air gaps is accompanied by high temperatures of the armature and pole face laminations due to excessive core loss. The obvious remedy for an insufficient air gap is to increase the gap by the removal of shims or liners under the poles, being careful to keep the gap uniform.

In modern practice, commutators will operate successfully with a surface speed as high as 6000 feet per minute. Above this value successful commutation is difficult to obtain as the brushes cannot follow the slight irregularities in the commutator surface and sparking will result. When sparking results from excessive commutator speed, a reactive or leading type brush holder should be fitted with an angle of from thirty to forty degrees from the vertical.

If the connection strips connecting the series and commutating coils are not arranged so as to prevent the forcing of the armature in one direction at all times when under load, sparking may result from a continuous pounding of the thrust collars or oil deflectors against the bearing linings and grooving of the commutator is very apt to follow. The current in the connection strips should be carried in opposite directions around the shaft so as to permit the armature to float freely in its bearings and not be affected by the fields set up by the current in the strips. Causing the current to flow in opposite directions neutralizes the magnetic effect because one field opposes the other. Where it is not convenient on machines already installed to change the connections to the fields so as to neutralize the magnetic effect, the line current may be carried around the shaft through a cable in a direction which will rectify the trouble and this remedy is often resorted to. The cable may be either cleated to the magnet frame or to the bearing housing.

ARMATURE TROUBLES

FAILURE OF INSULATION—SHORT-CIRCUITED AND REVERSED ARMATURE COILS—HEATING—DIRTY ARMATURE—LOOSE CORES

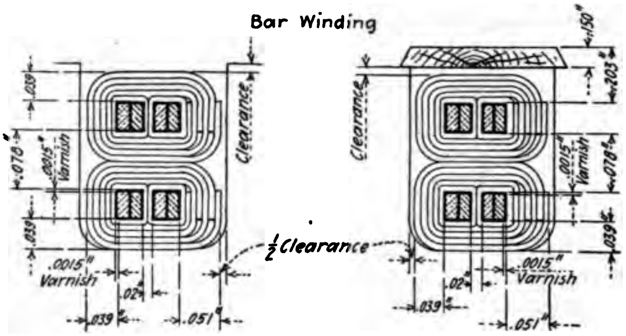
FAILURE OF INSULATION

Failures of insulation may be classified as local and general, depending upon whether the puncture or breakdown is restricted to a small section of the insulation or whether the fabric or insulating material is disintegrated and rendered useless over the entire coil. A failure of the insulation in the armature is first detected by a short-circuit or ground followed by smoke and high temperatures together with sparking at the commutator. Machines are designed to be equipped with kinds and thicknesses of insulation depending upon the nature of the service, which makes it inadvisable to load a machine beyond its normal rating unless the operator is familiar with the temperature limits of the class of insulation employed.

The following materials used in their natural state, that is, without treatment or impregnations, will withstand a maximum temperature of 95° Centigrade without damage: cotton, silk, paper and similar materials. When treated, impregnated with insulating varnishes, or immersed in oil, these materials will safely withstand a maximum temperature of 105° Centigrade.

Mica, asbestos and other materials capable of resisting high temperatures, will withstand a maximum temperature of 125° Centigrade. The use of materials of the lower temperature class as binders for the second or heat resisting type makes it necessary to keep the maximum temperature limit at 105° Centigrade for treated insulation and at 95° Centigrade when untreated, unless the binders may be destroyed after the windings are in place without damaging the remaining insulation. Pure mica, porcelain or quartz have no fixed temperature limits.

The following table gives the typical insulation representative of the best practice used on direct-current machines operating at voltages of 500 and below, where the normal guarantee of temperature rise does not exceed 35 to 40 degrees Centigrade followed by 25 to 50 per cent. overload for two hours with a temperature rise not to exceed 55 degrees Centigrade.



Cross Section Without Wedge

Cross Section With Wedge

FIG. 99.

BAR WINDING

Insulation for Armature Conductors in Slot Without Wedge

Around each conductor—Cotton tape butted and varnished.

Vertical separator 5 to 10 Mil paper.

Around each group of conductors—2¼-inch wraps varnished cloth, lap on side.

Around each group of conductors—Cotton tape butted and varnished.

Slot armor—Horn fiber at sides and bottom of slot.

Insulation for Armature Conductors Outside of Slot

Around each conductor—Cotton tape half lapped and varnished.

Around each group of conductors—Cotton tape half lapped and varnished.

This insulation requires a width clearance of 0.10 inch where two bars per slot are employed and 0.17 inch with eight bars per slot. The depth clearance without the wedge is 0.150 inch.

The table below gives the insulation as used on a maximum rated machine of 500 volts or more, that is, a continuous rating without overloads designed for a temperature rise of 50 degrees Centigrade. The insulation varies in the width clearance from 0.10 inch for two bars per slot to 0.16 inch where eight bars are used. The depth clearance is 0.17 inch.

INSULATION FOR ARMATURE CONDUCTORS IN SLOT WITHOUT WEDGE

Around conductor—Mica tape, half lap.
Around group of conductors—2¼ wraps mica paper. Lap on side.
Around group of conductors—Cotton tape, half lap, varnish.
Around group 1¼ wraps—Horn fiber. Lap on side.

Insulation for Armature Conductors Outside of Slot

Around conductor—Mica tape, half lap.
Around group of conductors—Cotton tape, half lap, varnish.

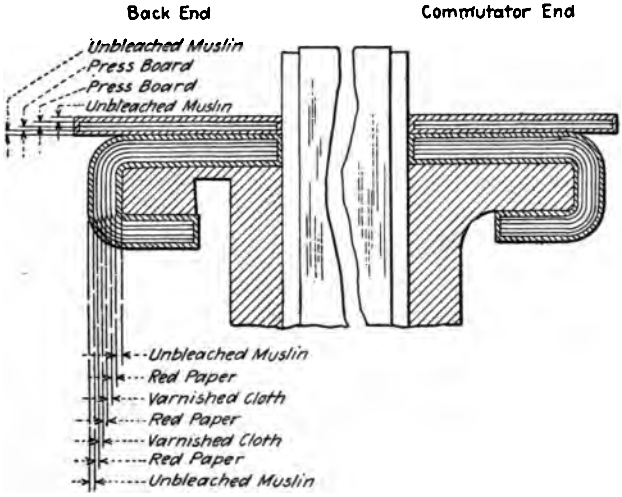


FIG. 100.—Sketch showing insulation for armature flanges.

The above sketch shows the method of insulating armature flanges and materials used. On high temperature or high voltage (1000 or above) units, heat resisting materials such as mica placed between sheets of horn fibre with all layers arranged to break joints should be substituted for the insulation shown.

Above 500 volts, the insulating thicknesses are increased corresponding to the increases of voltages and above 1000 volts, mica insulation should be used exclusively. Total width clearances in machines above 500 volts vary from 0.14 inch with two bars per slot to 0.2 inch with eight bars while the depth clearance not including the wedge thickness is 0.275 inch. Armature conductors made up of two or more laminations in multiple should have the individual laminations thoroughly varnished before assembling. Equalizer rings are insulated in the same manner as the armature windings to which they are connected. The insulation between upper and lower layers of end windings is made up of fibre where the voltage does not exceed 500 and of mica sheets placed between two layers of fibre with higher voltages.

SHORT-CIRCUITED AND REVERSED ARMATURE COILS

A short-circuited armature coil, usually caused by a failure of the insulation between the conductors and the ground, or more particularly between adjacent conductors resulting from movement of the coils in service will be evidenced by severe heating of the short-circuited coil, smoke and, if the action is allowed to continue, by the complete destruction of the insulation. The unit should be completely shut down immediately, (it is not sufficient to simply open the field-circuit as the residual magnetism will continue the action), and the location of the faulty coil determined by noting with the hand which conductor has the highest temperature. When the coil has been located a careful inspection should be made to determine the source of the trouble. Particular attention should be paid to the connections at the commutator and those segments directly connected to the hot coils to insure that the trouble is not at the surface before removing the wedges and binding bands preliminary to removing the coils. If a careful search fails to reveal any external causes for the short-circuit, the binding bands should be cut, the wedges removed and the coils carefully lifted out. Should no damage to the insulation on the coils be apparent, due to the excessive current which it has been carrying except at the point of break down, repairs may be effected by the application of insulating varnish, varnished cambric, oiled linen, varnish treated paper or sheet mica. Where the insulation on the coil has been severely burned or charred it is necessary to replace the coil as described on Page 242, or to entirely reinsulate it with any of the above materials. After any of these repairs have been made, the entire armature should be thoroughly baked out at a temperature not less than 100 degrees Centigrade until all solvents in the varnishes used have been driven out. The wedges and binding bands should then be replaced. Upon replacing the machine in service, a light load should be applied for several minutes while a careful inspection is made to insure against a repetition of the old trouble.

The probability of a machine developing armature trouble due to a reversed armature coil is very slight, especially if the unit has just been shipped from the factory, for practically all types are given a test before shipment. However, in replacing coils in service it is possible to connect in the coil reversed with respect to the other conductors, which causes the voltage generated in the new coils to oppose that generated in the remainder of the armature. This error does not occur in replacing form-wound coils made up of copper bars, for here the structure of the coil shows definitely which slot portion is to go in the upper and which in the lower winding section. It is impossible with bar windings to cross the leads and at the same time make connections with the commutator segments. Wire-wound coils, either form, or hand-wound composed of several turns per coil may easily have their leads crossed when the connections to the commutator are made with the result that the coil is placed in a reversed position with respect to the other conductors.

A generator having an armature containing a reversed coil cannot be brought up to full voltage easily under normal load conditions and it may require excessive field current to produce its rated voltage. The field margin is thus exhausted and it is impossible to hold the voltage at the required value under conditions of overload or in parallel operation. A motor operating with a reversed coil will exceed its rated speed since the counter electromotive force is reduced by the amount of voltage generated in the reversed coil and the difference must be compensated for by a rise in speed. A reversed coil may or may not produce commutation trouble depending upon the degree of liberality of design of the unit or whether one coil is but a small percentage of the total number of coils in the armature. The faulty commutation is evidenced by sparking at each set of brushes successively as the reversed coil passes beneath it.

Transposing the leads of the reversed coils where they are connected to the commutator segments, is the obvious remedy for a reversed coil in the armature.

HEATING

The two limits in the design of direct current machinery are those established by commutation and heating. Heating results from copper, iron and friction losses and even in a well designed machine these may vary from 5 to 20 per cent. of the total power output, depending upon the size of the unit. Modern machines equipped with varnish treated, fire proof and heat resisting insulation will not be damaged if a final temperature of 100° Centigrade is not exceeded. In older units, in which the special varnish treatments were not employed and such insulating materials as cotton, oiled linen and varnished cambric were made use of, 75 to 80° should be considered as the maximum safe operating temperature. Where the latter insulating materials are in use, higher temperatures are permissible if the entire insulation is treated with a bath of insulating varnish of a mineral or asphaltum base.

Iron losses in direct current machines exist principally in the armature core and air ducts are provided for the dissipation of the heat thus engendered. The core loss is directly proportional to the thicknesses of the laminations making up the core, the frequency of the generated current and the effectiveness of the insulation between laminations. Core heating is often occasioned by an insufficient air gap and this should be borne in mind when it is desired to operate a machine above its rated voltage, since an increase in speed or a reduction in air gap, while producing the desired voltage will also materially increase the core heating. In the rebuilding of a core the insulation between laminations must be made as perfect as possible, in order to reduce the eddy currents to a minimum, by the use of quick drying japan or by oxidation, that is, by simply permitting the laminations to gather an accumulation of rust where the preceding insulating material has been removed. Iron losses are also found to a lesser degree in the pole pieces, particularly at the pole faces. Copper losses (Current^2 × Resistance) in the armature and fields produce another source of heating and combined with that caused by the iron losses, present a trouble which must be combatted by successful ventilation. Inasmuch as the copper loss varies as the square of the load current, extremely high swings of load must be avoided unless the machine is designed for such service. Eddy currents producing heating in the armature conductors are guarded against and reduced by providing in the design for thin laminations of copper instead of a solid copper bar—each copper strip being insulated by a film of insulating varnish.

Failure to keep the air ducts clear and free from all deposits of dirt and grease will obstruct the proper ventilation with resulting high temperatures. If the heating generated by the iron and copper losses is not dissipated by a free and continuous supply of cooling air, the efficiency of the unit and its length of life will be greatly decreased. The lowering of the efficiency is due to the fact that the resistance of the conductors increases with a rise in their temperature. A unit which is not limited by commutation in regard to overloads may be operated satisfactorily during overload if the temperature is kept within the limits mentioned above by means of a fan mounted directly on the shaft or an independent blower unit. Should the commutator temperature be the limiting feature during overload, slots may be sawed in the ends of the bars, or ventilating vanes from 1 to 1½ inches high by 1 to

1½ inches wide by 1/16 to ⅛ of an inch thick, may be added on the outer ends of the bars to increase the radiation surface. It is customary to install the ventilating vanes by forcing them into slots in the bars and soldering to insure good contact. Attempts made to lower commutator temperatures by the use of separate blowers rather than by an increase of the radiation surface, have given disappointing results and no material advantage can be gained from such practice. Parts of prime movers such as engine eccentrics or fly wheel hubs, couplings, pulleys, gears and bearings should not be so placed as to obstruct the free passage of air to the commutator spider on the one end and the armature spider on the other, as these two points are the locations of the intakes for the cooling air passing to the revolving parts.

DIRTY ARMATURE

Failure of insulation resulting in grounds and short circuits in direct current machines is most frequently directly traceable to inattention and neglect of the proper cleaning of the unit; while high temperatures and flashing at the commutator can often be attributed to the same source. The creepage surfaces at both ends of the commutator and around the armature flanges, the air ducts in the core, spaces between adjacent coils, end windings, binding bands and wedges and all pockets where dirt and grease may collect should be subjected to a thorough periodic inspection and cleaning at least once each week. In the cleaning, the armature should be first blown out with compressed air or by means of a hand bellows, beginning at the back or coupling end and blowing toward the commutator. Parts of the armature inaccessible to the air blast, must be cleaned by hand by rubbing with a piece of waste or cloth. If the collections of dust and lint upon the surfaces and in the crevices have combined and become saturated with oil, grease or moisture, the air blast will be ineffective and the coating of dirt must be removed by rubbing with waste or cloth dampened in gasoline or kerosene. Lubricating oil should not be used for this purpose as it will attack the solvents in the compounds used in the insulating materials and will also provide a greasy surface for the further collection of dirt. Creepage surfaces, exposed end windings and pockets where dirt may collect should be given a coating of insulating varnish, applied after a thorough cleaning at least once each year and oftener where the armature is exposed to moisture in addition to the usual station dirt.

LOOSE CORES

It is very infrequently that a machine develops trouble due to a loose core, but where this difficulty is encountered, practically the only remedy lies in the rebuilding of the entire armature. The core may be tight and absolutely rigid when first installed but if subjected to a continuous vibration or series of shocks or frequent reversals, the laminations may become loose. Armature cores are built up in several ways, by mounting one piece laminations directly on a key on the shaft or spider and holding the assembled core with end flanges; by mounting the laminations on through bolts without a spider, in which case the end flanges are keyed directly to the shaft (used where the outside diameters or punchings do not exceed 40 inches) or by building up cores of rings of punchings made in several sections and used where the outside diameter exceeds 40 inches. In the last type, the spider supporting the laminations is fitted with arms machined to receive dovetails on the inside diameter of the laminations. In the first two constructions, where the cores become loose, the commutator leads or risers become broken by the relative movement between the core and the commutator and a thumping or grinding noise is noticeable with changes of load or speed. The core may be tightened by drawing up the through bolts or by the use of dowels placed so as to hold the end rings and punchings together and other dowels placed to prevent movement between the end rings and the spider.

In the sectional lamination construction, the fit of the dovetail in the spider arms must be perfect to prevent the sectional punchings from moving out due to centrifugal forces. This movement is particularly noticeable at the air ducts and here the slot armor as well as the armature coil insulation may be cut completely through. The loosening of a core of this construction will be accompanied by a pounding and grinding noise, noticeable at starting and stopping. Mechanical unbalancing will also be evident as the unit comes up to its normal speed. A trial by feelers will show which portion of the core has become loosened and should be made as soon as the noise is detected so as to prevent the destruction of the insulation by the protruding laminations. It is useless in such cases to attempt to dowel the laminations to the end rings and the placing of metal shims in the bottom of the slots under the armature conductors to prevent the outward movement of the punchings has proved unavailing. The core must be rebuilt and the dovetails shimmed where the machine work on the armature spider arms is found to be defective. At the air ducts a metal piece corresponding in shape to that of the dovetail should be put in position to prevent the buckling of the dovetail at this point and thus allowing the lamination to rise. This metal block should have the same thickness as the air duct in the core.

In rare instances of severe short circuiting in the armature, sufficient heat has been developed to burn out a large section of the laminations in the core. The mistake has been made in the replacement of such burned out sections of substituting a solid metal piece with the result that the immense amount of heat generated by the hysteresis and eddy currents soon melted the iron. Laminated sections should always be substituted when making repairs of this nature on the cores.

FIELD TROUBLES

Short Circuits and Open Circuits in Field Coils—Reversed Spools—Shunt Adjustment—Loose Pole Pieces—Compensating Windings.

SHORT CIRCUITS AND OPEN CIRCUITS IN FIELD COILS

Short circuits in field windings whether they occur in the shunt, series or commutating fields are due in practically all cases to a failure of the insulation between turns or layers. A short circuit in the shunt winding of a generator will cause a reduction in the generated voltage, since the ampere turns are reduced by the flow of the current directly from one turn to the next without passing around the core. In a motor, the speed will be increased by a short circuit in the shunt field due to the weakening of the field strength. All of the field coils including the defective one will show a higher temperature than under normal conditions since the field current is increased as the resistance of the field circuit is reduced by the short circuited turns. The failure of the insulation causing the short circuit may result from high temperatures or from the kick of the induced voltage when the field switch is suddenly opened. To insure against this latter trouble a small coil having a resistance equal approximately to that of the shunt field should be connected to the field switch and the field terminals in such a way as to allow the field to discharge through the resistance which is thrown in multiple with the field as the switch is opened. This discharge resistance is connected to additional clips fitted on the field switch so that the blade of the switch throws the resistance in the circuit at the instant the field is opened. Upon rewinding a coil whose insulation has failed due to high temperatures, it is inadvisable to wind the turns more than one and one quarter inches deep unless a ventilating air duct is introduced or the layers of wire are thoroughly filled with insulating varnish.

A short circuit in the series coil of a generator will cause the machine to drop its voltage and also to drop its load if it is operating in multiple with other units. A rise in speed will be noticed in a motor. In the commutating field a short circuit will be noted by sparking at the commutator, particularly at the stud affected by the defective coil although all studs may spark due to the increase of the current through the windings when the resistance of the field is reduced by the short circuit. The obvious remedy for a short circuited coil is to rewind and renew the damaged insulation although under emergency conditions if the short circuit occurs in the outside of the coil, it will suffice temporarily to insert insulating material or mechanical separators to keep the layers apart.

An open circuit in the field winding occurs in some cases where the temperature is allowed to reach a point at which the soldered joints will fuse and run but usually results from accidents or rough handling. The voltage of a generator will drop and the speed of a motor will increase to a dangerous point unless the circuit breaker or fuse opens the circuit. If an open circuit is caused by damage while the unit is not in operation, the generator will fail to pick up and the motor will refuse to start. A coil in which an open circuit occurs must be repaired by completing the circuit so as to connect the damaged coil in its proper relation. The coil cannot be bridged over or cut out for high temperatures and commutation trouble will immediately set in.

Grounds in the field circuit may cut out or open circuit one or more coils by allowing the current to flow through the grounded path instead of the field circuit. The generator or motor with a grounded field coil behaves as though it contained a short circuited or open circuited coil and for this reason a test should be made for grounds as soon as the symptoms appear instead of attempting immediately to treat the coil for a short or open circuit. The test and repair for a grounded coil is explained on pages 221 and 222. The coils may be grounded temporarily due to moisture where the unit is located in a damp place and not operated for a long period of time. Such a ground may be readily removed by thoroughly drying out provided no attempt is made to operate the machine before the drying process. The application of voltage to a damp or wet machine results in a permanent ground necessitating extensive repairs.

A ground or short circuit occurring between the shunt and the series field will cause a sudden drop in voltage in a generator and a rapid change of speed in a motor. The fuses in the line may be blown out or the circuit breaker opened if the ground is so located as to leave very little resistance in the circuit. This may readily occur if the contact point between the two fields is located very close to the opposite polarity, that is having but a small percentage of the shunt turns left in the circuit. A portion of the shunt field may be burned out due to overheating even though the current value is not great enough to open the protective devices.

REVERSED SPOOLS

Reversed spools are rarely encountered on machines which have just come from the factory since they are given a polarity test before shipment. In assembling large machines for which the coils are shipped separately or in replacing defective coils with spares, there is a possibility of trouble from reversed polarity. It is also possible to install a new shunt coil with armature end placed against the frame in which case the polarity will be wrong even though external connections are correct. Series or commutating field coils may be reversed by the improper connection of strips between spools.

A generator with a reversed shunt coil may fail to pick up and will always fail to generate its full rated voltage, while a motor will run at a speed above normal and refuse to take its full load without excessive sparking. A reversed series coil on a generator will cause the voltage to drop as the load is applied since the series field will be opposed to the shunt windings. A compound wound motor will speed up upon reversing one of its coils and the armature will tend to become overloaded. A reversed coil in the commutating field circuit will be noted even upon the application of fractional loads on a motor or generator by severe sparking at the commutator.

Reversed series or commutating coils can be easily detected by a drop in voltage or faulty commutation as the load comes on while the reversed shunt spool may be found by noting the failure to pick up or to generate full rated voltage before load is applied. The use of a compass to locate a reversed shunt coil is a quick but not always certain method since the compass needle may become reversed and for this reason it is advisable to test the shunt polarity by bringing the field up to its normal strength and introducing two nails on adjacent pole tips, noting whether they attract or repel each other. This test should be made around all pairs of poles and when the point of reversed polarity is located, the nails will repel each other showing that the poles of like polarity lie adjacent. The connecting wires should then be changed to reverse the direction of the current to establish the correct polarity.

SHUNT ADJUSTMENT

Both series and commutating fields are fitted with an adjustable resistance made of German silver and provided with taps or iron grids connected in series or multiple.

The adjustment of the commutating field is made at the factory.

This field is designed to secure good commutation and no adjustment is ordinarily required in practice to suit load conditions. However a service constantly requiring rapid changes of load may necessitate a readjustment of the commutating field with a view to eliminating or reducing to a minimum the noninductive resistance across the field. This may be accomplished by increasing the air gap by the removal of shims or liners between the commutating pole pieces and the frame but in most cases, it is advisable to replace the iron shims or liners with pieces of zinc or brass, keeping the air gap at the armature end as close to the factory adjustment as possible.

Instability of speed in a motor and occasionally a weak series field in a generator may be traced directly to excessive commutating field strength which does not upset the commutation on account of the liberal design of the unit with respect to commutation constants but which saturates the magnetic circuit to such a degree as to nullify in a measure the effect of the series field. Here a shunt should be installed across the commutating field even though the factory adjustment omitted such regulation. Rapid load changes such as are met in railway service where adjustments for full field, that is without shunts, cannot be made by changing the air gap demand shunts of the inductive type. The inductance of this shunt must be equal to the inductance of the commutating field circuit and in such cases it is best to get the advice of the manufacturer of the unit or to order directly from the factory an inductive shunt to meet the requirements.

The shunt field is fitted with a regulating rheostat for adjusting voltages at no load and equalizing loads on machines operating in parallel where the units are shunt wound. On compound wound generators or motors the voltage or speed regulation is accomplished by the adjustment of the strength of the series field. Adjustable shunts are furnished as it is nearly always necessary to change the voltage or speed regulation to suit the exact power requirements after the machine is installed. Adding resistance to the shunt increases the strength of the series field which raises the voltage of the generator and reduces the speed in a cumulative compound wound motor. Subtracting resistance, on the other hand, weakens the series field with the opposite effect on voltage and speed. A change in the air gap under the main pole pieces may be introduced to advantage where the voltage or speed is unstable but very little change, if any, can be made in the effect of the series field by the change of gap and this method is usually unavailing where the strength of the series field is in question.

When adjustments in the commutating or series fields are being made, care should be exercised to allow the unit to operate between trials for a sufficient period of time to bring the temperature of the shunts to a running heat since the resistance varies with the temperatures in both field and shunt.

The cold adjustment should hold when the unit has reached its normal working temperature.

LOOSE POLE PIECES

Loose pole pieces either main or commutating, are rarely met with in practice unless improper attention has been given to the tightening of the pole piece bolts when assembling the unit or in adjustments requiring the removal of shims. In the latter instance, the length of the bolts may be such as to bottom in the hole of the pole piece before the head comes in contact with the frame, permitting movement of the pole piece. Spool bodies made with a fixed length may also prevent sufficient tightening of the pole piece against the frame after shims have been removed. Loose pole pieces will not remain in their true position and an unequal distribution of flux will result due to the varying contacts between the pole and the frame. Pole pieces not on the vertical will sag bringing the tips of adjacent poles closer together than other parts of the magnetic circuit occasioning excessive flux leakage as well as a general magnetic inequality. Unless the loose pole pieces are tightened to insure a good uniform contact between the poles and the frame, good voltage or speed regulation and successful commutation cannot be expected.

COMPENSATING WINDING

Compensating or pole face windings are in effect a part of the usual commutating field, the turns being carried or supported in the faces of the main poles instead of being wound around the commutating pole piece. Shunt adjustments on machines equipped with compensating windings are made by placing a resistance across the turns on the commutating pole proper, allowing the pole face windings to carry full line current. Grounds or short circuits in the pole face winding or between the connection strips connecting the pole face conductors, will result in faulty commutation and for this reason as well as in the interest of ventilation, units should be kept free from all collections of foreign matter by a regular and systematic blowing out with compressed air or hand bellows. It should be remembered that most machines equipped with pole face windings are built with smaller diameters, shortened field cores, closer air gaps and clearances, thus making absolute cleanliness a paramount necessity.

MOTOR TROUBLES

REFUSAL TO START—REVERSED ROTATION—SPEED REGULATION AND ADJUSTMENT.

REFUSAL TO START

If a motor, whether new or old, refuses to start, the first check to be made is to insure that voltage is being supplied to the motor terminals at its rated voltage. The starting rheostat should be examined for open circuits and make sure that the shunt field is connected on the power circuit, so that the starting resistance is not in series with the shunt field. If a further inspection shows that the external connections are correct and all terminals tight, and the motor still refuses to start on the very first application of voltage, a test should be made to determine whether or not the field is excited. This may be done by bringing a magnet close to the shunt windings or by testing for magnetism in the pole tips, using a nail or steel rod. The failure of excitation may be due to an open circuit in the windings, loose or poor contacts or a ground.

The armature circuit may be open due to a broken commutator lead or an open circuited coil and if the armature is turned over by hand with the voltage applied, the break in the circuit will be bridged by the brushes on the commutator and the motor will run if not heavily loaded but faulty commutation and unsatisfactory operation will follow. The open circuit may exist between the commutator and the brushes due to insufficient spring pressure, binding of the brushes in the holders, or in small units, to a dirty commutator surface.

A shunt wound motor or a compound wound motor with its series field connected so as to oppose the shunt winding, may refuse to start on account of load conditions or high friction. Belted motors frequently require a start by hand to overcome the effect of friction. Machines which have remained idle for long periods of time should have the armatures revolved to reëstablish the oil film in the bearings before throwing on the load. A new installation may require a readjustment to increase the series field strength on a cumulative motor in order to increase the starting torque where the unit is required to start under load. A differential motor may necessitate the reversal or disconnecting of the series field to cause it to start under load.

After long periods of operation or melting of babbitt in bearing linings due to overheating, the shaft centers may be lowered to a point where the armature laminations rub on the pole pieces. The air gaps should be checked periodically in order to avoid such trouble for although the motor may be started without damage where there are no binding bands on the core portion, it will vibrate considerably on starting and run with excessive friction. The armature will also run hot due to the unbalanced electrical circuits occasioned by the inequality of the air gap. After a replacement of defective field coils, it is well to check the polarity before applying voltage to the armature as the motor will refuse to start if any of the poles have been reversed. A reversed series field will be noticed in the speed regulation rather than in the refusal to start.

REVERSED ROTATION

After the motor has been started, it may revolve in a direction opposite to that desired. The direction of rotation of a shunt motor may be changed by simply reversing the leads to the shunt field or to the armature terminals but both must not be reversed at the same time since the relative direction of flow of the armature current and the field flux will not be changed. A reversal of the lines attached to the power bus will not reverse the motor. To reverse a compound wound motor, both the shunt and the series fields must be reversed or the leads to the armature exchanged as explained above. A reversal of the shunt field only may cause the unit to race under load on account of the differential effect of the series field. Reversing the series field only will weaken the starting torque to such a degree as to make starting difficult and operation under load unsatisfactory.

A series motor is reversed by reversing the connections to the armature or field circuits and since both circuits take full load current, the choice is optional with the operator. On most shunt and compound wound motors, it will perhaps be easier to shift the connections to the fields.

SPEED REGULATION AND ADJUSTMENT

The speed of a constant voltage shunt or compound motor depends upon its field strength while a series motor supplied with constant voltage has a different speed for every load. A shunt wound motor upon being started may revolve at a speed above the required value and where no margin is provided in the winding for an increase in the field strength, the speed may be reduced by placing shims or liners between the main poles and the frame to reduce the air gap. The reduction of the gap should not be carried beyond a safe mechanical clearance between the stationary and revolving parts and it should be remembered that the reduced gap will increase the core heating. Where a permanent resistance has been inserted in the circuit to obtain the rated speed, this may be reduced or removed to strengthen the field, bringing the speed down. The speed may be too low in which case no attempt to raise it should be made until the running temperature has been reached as the motor will be found to speed up as the resistance of the shunt field rises with the temperature. All factory adjustments are made on a basis of hot fields. A rheostat may be used to weaken the field or a permanent resistance may be installed for this purpose. On commutating pole motors, the speed may also be raised provided the commutation permits, by shifting the brushes slightly backward, that is, against rotation. It should be noted that the brush position cannot be changed on reversible motors for purposes of speed regulation unless the reversal is infrequent and the brush position is changed for each direction of rotation.

Speed adjustment on a compound wound motor is effected by manipulating the series field, strengthening it when the speed is too high and weakening it at reduced speeds. Commutating pole motors, developing trouble from speed regulation, not easily remedied by changes in the series excitation, will operate to advantage with a reduction in the strength of the commutating field without upsetting commutation. Series motors have a fixed speed for each load. Reductions in the fixed speed values may be brought about by adjustment of the air gap. Increase in the speed may be accomplished by placing a shunt across the field winding thus weakening the field strength.

The air gap of variable speed motors should be made as large as possible to insure good regulation at the high speed or weak field ratings because the preponderance of the excitation is required at the air gap instead of in the remainder of the magnetic circuit. In emergency situations, field coils may be connected in multiple instead of in series, which will materially increase the field strength and secure substantial reductions in speed, but temperatures should be closely watched to prevent damage from overheating. External fans are used to advantage in such emergencies to keep the temperature rise within safe limits. Exceeding an ultimate temperature of 95 degrees Centigrade where untreated wire is fitted, or 105 degrees Centigrade where treated or compounded materials are employed, will necessitate the stopping of the unit.

GENERATOR TROUBLES

FAILURE TO PICK UP—BUILDING UP WITH WRONG POLARITY—PARALLEL OPERATION—HEATING.

FAILURE TO PICK UP

A generator may fail to pick up or build up its voltage if its speed is very much below the rated value. It is well, therefore, at the first indication of this trouble to make sure that the speed of the generator is approximately equal to that given on its nameplate. The field rheostat should be turned to its "Off" position, that is, with all resistance out of the field circuit, and the contacts examined for loose joints and dirty connections, particularly at the terminals of each field spool. In the finish of a machine at the factory, the shunt field terminals may be filled with paint or varnish which will increase the resistance of the circuit and prevent the unit from building up its voltage. The field rheostat should also be examined for open circuits or high resistance contacts between the moveable arm and the button terminals. The commutator surface should be inspected to guard against collections of oil, grease or dirt which will open the circuit or introduce a high resistance between the brushes and the commutator. A good fit of the brushes on the commutator is necessary as well as sufficient spring pressure to insure good contact.

The voltmeter connected to the armature will show the voltage generated due to residual magnetism. If upon closing the shunt field circuit the voltage drops instead of rises, the shunt field should be reversed because the magnetic flux generated by the shunt field is opposing that due to the residual magnetism and the generator cannot pick up. The residual magnetism may have been lost entirely if the unit has been placed in the vicinity and the influence of other excited fields, particularly while being prepared for shipment, or has been subjected to excessive vibration or sudden jarring in transit or handling. The brushes should be lifted to prevent a short circuit and direct current voltage from some external source should be applied to the terminals of the shunt field for a few seconds in order to restore the residual magnetism. The voltage may be secured from another generator, a storage battery or a number of dry cells in series. In the latter case where the voltage is low as compared with the machine voltage, it is sometimes necessary to apply the battery connections to two or more spools instead of to the entire number in series. If a compound wound unit which has lost its residual magnetism is to operate in multiple with other machines, the equalizer switch may be closed as well as the necessary line switches to complete the circuit from the live machine through the equalizer and series field to the bus bar, and the flow of current through the series field will restore the residual.

BUILDING UP WITH WRONG POLARITY

In an ungrounded power or lighting circuit the polarity with which the generator builds up is of no consequence because the polarity in no way affects the ordinary incandescent lights or the direction of rotation of direct current motors. However, instruments on switch boards, circuits with the negative side grounded, storage battery charging and electrolytic processes all require a fixed polarity for satisfactory operation. Should a generator build up its voltage with the wrong polarity the residual may be changed by applying voltage from a separate source and the correct polarity will thus be established. It is sometimes more convenient especially with compound wound generators operating in multiple to correct the polarity by closing the equalizer and line switches where necessary to complete the circuit.

PARALLEL OPERATION

A new generator installed to operate in parallel with other units should be given a polarity test before any line switches are closed to insure against connecting in series instead of multiple with the danger of heavy overloads of current, high voltages, flashing and burning of the commutator and brush rigging. A shunt wound generator may have its polarity corrected by applying current from the other units to the shunt field in such a direction as to reverse its residual magnetism. The residual of a compound wound generator may be reversed in a similar manner but it may be more conveniently done by using the equalizer circuit to deliver current to the series windings.

The newly installed unit may fail to take its share of the total load if the speed regulation from no load to full load is greater or less than that of the old units, and this must be corrected by adjusting the speed of the prime mover. The location of the brushes back of the neutral against rotation on a commutating pole machine will cause a generator voltage to rise sharply when load is applied and a heavy overload usually results. Unless the circuit breakers open or the prime mover drops in speed on account of the overload, the generator voltage will rise to a point which may cause the other units in parallel with it to operate as motors, thereby increasing its own load. If the brushes are ahead of the neutral in the direction of rotation on a commutating pole machine, the generator will refuse to take load and its voltage will drop sharply when load is applied.

Equal division of load in multiple operation cannot be obtained unless the compounding of the individual units is similar. For example a generator overcompounded from 120 volts at no load to 125 volts at full load or 250 volts at no load to 275 volts at full load, should not be connected in multiple with generators flat compounded from 125 volts at no load to 125 volts at full load or from 275 volts at no load to 275 volts at full load as the overcompounded generator will take all of the load due to its rising voltage characteristic, as compared with the flat voltage characteristic of the other unit. The compoundings may be made similar by readjustment of the series field shunts where such shunts are furnished, but it is also possible to adjust the compoundings by shifting the brushes on machines of the commutating pole type where the commutation is not affected. Shifting the brushes in the direction of rotation causes the voltage to drop with load, while against rotation, produces the opposite effect. Successful parallel operation depends upon a drooping characteristic voltage curve in all the units connected in multiple. Overcompounded generators cannot be operated in parallel with synchronous converters since overcompounding is practically impossible on the converter and the generators will take all of the load. No trouble is experienced when the generators are flat compounded.

HEATING

The most general cause of heating in a direct current generator is overloading, which in many cases comes as a result of false indications of switchboard meters. Short circuited armature coils, grounds, leakage of current due to moisture, faulty ventilation, accumulation of dirt or grease and poor commutation also produce overheating of the generator. Thermometers should be attached by means of putty to the stationary parts such as the fields, brushes, bearings and connection strips in order to determine the true temperature when there is any suspicion of overheating rather than to depend upon the hand. While an approximate temperature of the revolving parts may be obtained by placing thermometers at the discharge of air ducts in the core and end windings, the true temperature cannot be obtained without shutting down the unit and quickly applying the thermometers. If the temperatures do not exceed 95 degrees Centigrade where the insulating materials are untreated, or 105 degrees Centigrade for treated materials, no damage from overheating will result upon continued operation although it should be borne in mind that the efficiency and length of life of the machine are increased to a great extent if it is run at a low temperature. Extreme overloading will incur the added damage and commutation trouble on account of flashing.

SHAFT AND BEARING TROUBLES

Shaft Pitting—Oil Rings—Bearing Linings—Oil Slingers—Bearing Fitting.

SHAFT AND BEARING TROUBLES

Due to the absence of reciprocating parts very little trouble is experienced with bearings and shafts on electrical machinery, when the rubbing speeds and pressure are kept within the limits already given. Heating, however, may appear due to shaft pitting, the failure of the oil rings to function properly, loose babbitt and the improper adjustment of the armature and field for end play.

Shaft pitting comes as a result of a flow of current through the shaft, bearings and base which form a low resistance path. The oil film in the journal is a good insulator and the flow of the current is usually from the shaft to the oil ring resulting in the scoring of both. The scoring on the shaft gradually spreads and the rough surface drags the babbitt lining causing high temperatures. The current usually flows through the shaft as a result of leakage flux cut by the armature spider and shaft. The most reliable remedy for the pitting lies in stopping the flow of current by insulating one or more of the bearing pedestals at the junction of the pedestal and the base with mica sheets between fibre layers having a total thickness of from 1/16 to 1/8 of an inch. In addition to this insulation it is necessary to insulate the dowel pins and holding down bolts by fibre sleeves and washers. Unless the edges of the bolt holes in the base and the bottom of the bearing pedestal are chamfered off or countersunk to provide a creepage surface of at least one half an inch, the insulation will usually fail around the holding down bolts at the junction of the two surfaces due to moisture or collections of dirt. It is unnecessary to insulate all bearing pedestals on a unit but just a sufficient number to interrupt the path of the current. On two bearing machines, it is sufficient to insulate but one bearing while with three or more bearings all pedestals should be insulated except one. Units subjected to severe flashing may develop pitting trouble with the pedestals insulated due to the flow of line current to ground. Here grounding rings should be placed on the shaft preferably on the machine side of the bearing housing fitted with a low resistance brush grounded in such a way as to prevent the current from passing through the bearing. Grounding rings are usually made of copper or brass fitted directly to the shaft at any convenient point. Units equipped with ball bearings are particularly susceptible to trouble from pitting from either of the above-mentioned causes.

The function of the oil ring is to raise the oil from the oil well to the shaft surface and to do this it must be kept in continuous motion. If the oil ring revolves too slowly the oil will run back into the well before it reaches the shaft. If on the other hand the ring revolves at an excessive speed the oil is thrown into the bearing housing. For these reasons in case of replacement, it is advisable to install the same type of ring as that originally furnished. Many cases of bearing trouble can be traced directly to the use of wire and chains in place of the correct ring. Such substitutes should be used in emergency cases only. While oil rings may always be used where the machine operates continuously in a horizontal position, waste packed bearings are necessary where the unit constantly shifts in position as the rings will bind or catch in the grooves. The waste must be kept thoroughly saturated with oil and a screen made up of perforated metal should be placed so as to rub against the shaft at the bottom of the waste pocket to prevent small particles of waste from being carried underneath the shaft and forming burned rings with resultant heating.

Bearing linings, if improperly anchored may become loose and cause a rapid heating of the shaft and bearing. The movement of the babbitt may be detected on the ends by noting the oil oozing out between the lining and the housing. The movement may also be noted by placing the tips of the fingers at the junction of the babbitt and housing. Such a bearing should be immediately removed from service and rebabbitted, taking care to anchor the lining by dovetails.

If the end play is not properly adjusted and the armature fails to float in the bearings, the end thrust of the armature will cause the oil slingers on the shaft to rub against the end of the bearing housing or lining. This condition may also result from improper alignment or failure to level the base on the foundation. Where the cause of the end thrust in one direction is magnetic, it may be remedied by moving the magnet frame along the shaft in a direction opposite to that of the end thrust.

When a bearing surface becomes damaged or roughened from any cause or when the temperature reaches a point where the babbitt wipes or the bearing freezes, it is necessary to rebabbitt and refit the lining to the shaft. In many cases this must be done in a very short time and a satisfactory job cannot be done by the scraping and trying method. In such emergencies the bearings may be fitted quickly by removing the high spots with a scraper after which the bearing cap may be put into place but not bolted down too securely. A mixture of lubricating oils and pulverized hand sapolio or powdered pumice stone may be slowly poured into the sight holes in the bearing while the shaft is slowly revolved. The mixture should be supplied continuously allowing the surplus to drain from the oil well. The bearing will be quickly fitted in this way after which it must be thoroughly flushed with pure oil and all of the grinding material removed. The bearing cap should be tightened from time to time as the bearing wears in until the normal operating position is reached.

NOISE

Worn Bearings—Loose Armature Core—Movement of the Commutator—Unbalanced Armature or Pulley Belt Noises—Brushes—Windage and Magnetic.

NOISE

Undue noise in direct current machines results from both mechanical and electrical defects. Parts may become loosened in practice, due to shrinkages of insulation, such as field spool collars and bodies, bushings or collars around the brush rigging and armature coils. Loose nuts, bolts, screws, binding posts, connection boards and in exceptional cases armature punchings and commutator parts may rattle, squeal or thump during operation. The bearings may be worn to a point where the shaft runs very loosely in them producing a constant knocking sound or the wear may even have continued until the armature core comes in contact with the pole faces.

Noise is practically always an indication that something is wrong and while it, in itself, may not be considered as a defect, it is very liable to be the forerunner of a serious trouble. An examination should be made immediately to determine its cause. Neglect of the machine's natural warnings may permit the trouble to develop until it is necessary to make extensive repairs. Parts which have become loosened can be detected by feeling or listening while operating under normal conditions. Varying the load or changing the speed will often magnify the noise and make it easier to locate the point of trouble Once located, the remedy consists in tightening up the loosened parts and where necessary, as around the field coils and brush rigging, shims or liners of insulating material may be inserted. Badly worn bearings should be rebabbitted throughout while slightly worn bearings may be repaired by removing the liners between the upper and lower halves and tightening the cap. It is usually found that the lower half has worn more than the upper and a liner should be placed under the foot of the bearing pedestal or support to equalize the air gap. Where the armature conductors have become loose due to a shrinkage of insulation, the binding bands and wedges should be removed and spacers of fibre, mica or insulating material placed on top of the bars to make up for the shrinkage. A loose armature core, that is, loosened laminations, is generally evidenced by a thumping or grinding sound particularly noticeable when starting or stopping and immediate treatment should be given as outlined on page 195. Movement of the commutator will also produce a thumping noise and if allowed to continue, the commutator leads will be broken. The commutator bolts holding the spider in place should be tightened and in some cases it may be necessary to drill a hole at the joint between the commutator and armature parts and to insert round steel dowels or keys.

An unbalanced armature or pulley will set up a vibration of the entire unit and after a very short period of operation the bearings will wear excessively permitting an eccentric motion of the revolving element. Accompanying the vibration will be a pounding noise in the bearings, a rattle of the oil rings and a chattering sound at the commutator as the brushes try to follow the eccentric motion. The unit should be removed from service and the cause of the unbalancing determined. The armature and the pulley may be balanced by the addition of weights as previously described. The pulley, if tightened on the shaft by means of set screws or a key may need recentering, especially if the size of the shaft is not exactly the same as the bore of the pulley, in which case thin metal collars are fitted.

A noise caused by the striking of the belt or pulley against the bearings of the machine is easily remedied by mounting the pulley a little further out on the shaft so as to make the contact impossible. A laced or jointed belt will produce a periodic pounding at each revolution when the lacing or joint comes in contact with the pulley. An endless belt should be substituted, and it may be added should always be employed on electrical machinery. If the belt is loose or insufficiently tightened for the load or to accommodate sudden swings in load, a squeaking noise at the pulley will be noted accompanied by a flapping and scraping at the middle point of the belt, on the floor or at the machine base. In case of overload, the load should be reduced or the belt tightened by means of an idler or sliding rails. If this does not prove an effective remedy, a wider pulley and a wider belt must be substituted. In an emergency, where the bearing temperatures will not permit tightening of the belt to carry the load without squeaking, the noise may be eliminated by stopping the slipping of the belt. This is accomplished by rubbing a bar of turpentine or yellow washing soap on the belt surface which comes in contact with the pulley. The soap should be applied without oil or water as such application will increase the slippage and the belt may leave the pulley.

Incorrect brush angle, defective brushes or a roughened commutator surface or collector rings produce a harsh, disagreeable noise readily located at the commutator or rings. The brush chatter and hissing may come from hard spots in the brushes or from an excessive slant or brush pressure while the roughened commutator surface may in addition provide a singing and screeching noise. The application of a lubricant to the commutator surfaces may relieve this condition temporarily but continued use of the lubricant in any form will eventually destroy the mica insulation in the commutator and dirty its surface. The brush angle should be corrected or a new set of brushes substituted or if the commutator surface is at fault, it should be subjected to a smoothing process.

It is difficult to discriminate between the noises due to windage and those due to magnetic disturbance. Loose laminations in the pole pieces, particularly at the tips will vibrate and set up a humming sound while a similar noise is created by the windage of the armature due to the impinging of the air from the air ducts in the armature against the pole tips. Units equipped with pole face conductors supported by holes or slots in the pole faces are very susceptible to magnetic noises due to a vibration of the tips of the laminations in the projections between the pole face slots. A remedy for this has been found in securely anchoring the first inch of laminations on either side by drilling and inserting a machine screw. At the edge of the pole tip, where there is insufficient stock for the insertion of the screw or rivet, spot welding may be used to advantage. Where the main poles on a machine are made up of laminations assembled with open spaces in the pole tips in order to reduce the iron in them, and arranged by cutting back the tip on every other lamination, the hum from magnetic vibration and the increased windage is very noticeable. Since the introduction of a metal anchor of any description in the pole tip would defeat the purpose of the spaced laminations, it is necessary to fill the spaces with putty, paint or a compound which will harden in place and not melt or shake out. Should this remedy fail, the noise is purely magnetic and a slight chamfer of the pole tips extending from one to one and one-half inches back toward the center of the pole will in many cases eliminate the trouble. A change in the air gap is also effective as the amount of fringing is changed and an even number of slots and teeth are in the field flux at all times. Noise directly traceable to windage caused by the fan effect of the commutator leads, end clips, equalizer windings and supports may be materially reduced by the application of canvas heads or barriers arranged to interrupt the flow of air but the sound should not be diminished at the expense of good ventilation. The unit may be totally enclosed to obliterate the noise, in which case a supply of cooling air must be furnished by external blowers or fans. Sound proof rooms are also recommended where machines are operated in office buildings or residential districts.

CHAPTER VIII

MOTOR AND GENERATOR TESTS AND REPAIRS

INSULATION RESISTANCE—GROUNDS—OPEN CIRCUITS—SHORT CIRCUITS—SATURATION-ADJUSTMENT OF COMMUTATING FIELD—COMMUTATION—VOLTAGE REGULATION—SPEED REGULATION—HEAT RUNS—CORE LOSS—EFFICIENCIES—BEARING INSULATION—STARTING TEST—HIGH POTENTIAL TESTS—REPAIRS.

INSULATION RESISTANCE OF MOTORS AND GENERATORS

The insulation resistance of machines should be measured before starting for the first time, or after standing idle for a considerable time in a damp place.

The following methods give a ready means of measuring the resistance when a bridge or megger is not available.

Connect one side of a direct current source of power to the windings to be tested; connect the other side of the direct current circuit to a portable voltmeter and then read the voltage when the free side of the meter is connected to the other side of the circuit where it is attached to the windings. Call this reading "V." Then connect to the frame of the machine, being careful to get a good contact; call this reading "V_1." Then

$$r \text{ equals } R\left(\frac{V}{V_1} - 1\right)$$

where r equals the resistance of the insulation, and R equals the resistance of the voltmeter itself. This value is usually given inside of the cover of the volt-meter box.

Before using power from a commercial circuit for testing insulation, tests should be made to determine if the supply circuit is grounded. One side of the circuit must be free from grounds and the ungrounded side should be used in series with a voltmeter in taking resistance readings.

It is impossible to give any hard and fast rules that will cover all classes and sizes of machines, and the results must be used with judgment and common sense.

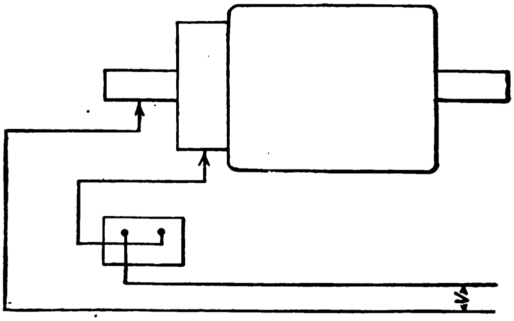


FIG 101.—Sketch showing method of testing resistance of insulation.

We consider the insulation resistance of a machine as indicating little more than the condition of the insulation as regards moisture. The rate of change of the resistance as the machine is being dried is, perhaps, the best indication as to when the drying has been carried far enough.

The following approximate rule has been developed; it should be understood, however, that this formula is to be used merely as a guide.

FOR DIRECT CURRENT GENERATORS

$$R_1 \text{ equals } \left\{ \left(\frac{300{,}000}{I_m} E_m \right) \text{ plus } 150{,}000 \right\}$$

where

R_1 equals Insulation resistance in ohms,
E_m equals Rated normal voltage of machine,
I_m equals Rated normal current of machine.

In accordance with *A.I.E.E.* Standardization Rules, when the machine is dry and clean, the insulation resistance in megohms should not be less than the voltage of the machine divided by the kilowatt rating plus 1000, or

$$\text{Resistance equals } \frac{\text{Rated Voltage}}{\text{Rated kw. plus 1000}}$$

GROUNDS

A test of the insulation resistance of the armature conductors, field windings or current carrying parts with respect to the iron portion of the machines, as outlined on page 219 is the most direct way of detecting grounds. Where a voltage supply is not available, a magneto testing set with one terminal connected to the live part of the machine and the other in contact with the frame, will ring upon the turning of its crank if the live part is grounded at one or more places.

When the unit behaves as though a ground or grounds existed in its stationary or revolving parts, the ground test should be applied to the machine as a whole. Lifting the brushes from the commutator and repeating the test individually on the stationary and revolving elements will indicate the location of the ground with respect to the division of the machine. If a ground is found to exist in the stationary part the search for the exact location must be continued by separately testing the individual elements such as field spools, brush rigging, connection boards and shunts.

Should the general test indicate the presence of a ground in the armature, a test for the exact location of the defect can be made by disconnecting the armature conductors at the commutator and applying the insulation or magneto test to each individual coil. To avoid the necessity of disconnecting all of the armature leads from the commutator it is advisable to test the coils in sections. It should be remembered that the equalizer rings on multiple wound generators must be disconnected while applying this test. If two or more grounds exist in the armature the most expedient test to apply is the drop of potential method. A fixed current is supplied to adjacent commutator segments successively and the voltage drop read on the low voltage scale of a voltmeter. Coils showing a drop of 10 per cent. or more below the average indicate the location of the grounded points. The brushes should be raised during this test but it is not necessary to disconnect the conductors at the commutator or equalizer taps. Should the drop on all coils prove to be approximately equal, the ground will be found to exist in the commutator which requires that all armature leads be disconnected and the individual bars tested from bar to shaft. The drop of potential method has proved unsatisfactory in so many instances that it is usually more efficient to disconnect the individual coils or sections of coils and locate the ground by the insulation or magneto test. Where a high potential testing set is available, voltage may be applied and held until smoke appears at the point of ground, but this method increases the damage to the insulation and thus augments the difficulty of making repairs at the grounded point.

Where a galvanometer is available, a low resistance ground may be quickly and accurately located by the following method: A low voltage current is passed through the armature winding from a commutator bar to the one adjacent to it, which is sufficient to give a deflection on a galvanometer or millivoltmeter. A line is connected to a galvanometer to ground, the other galvanometer connection being placed on one of the commutator bars. Then pass the supply and galvanometer leads from segment to segment, until a full deflection is obtained and zero reading when the leads are moved one segment further. The grounded coil then lies between the bars, for which full deflection was obtained.

OPEN CIRCUITS

An open circuit in the field winding of a generator is located by cutting out one spool at a time by short circuiting the terminal with a low resistance copper wire. When the copper wire is applied to the spool in which the defect occurs, it will bridge the break and the unit will begin to pick up. The generator should be operated at its normal speed during this test. The field of a motor is tested for an open circuit by closing the shunt field and repeating the process outlined above. When the field circuit is closed by the testing wire, an arc may be drawn which indicates that the circuit has been completed around the break.

A test for broken leads is made by substituting a piece of sheet metal which touches one commutator bar at a time for one of the regular brushes, after first thoroughly cleaning the commutator surface. A battery having a low voltage and a low resistance is then connected to the metal brush and to the carbon brush through an ammeter and the armature turned very slowly by hand so that the metal brush makes a good contact with each successive commutator bar. A break in either of the two leads soldered to a commutator bar is shown by a reduced reading on the ammeter. A zero deflection of the ammeter will indicate a break in both leads when contact is made between the metal brush and the segment of the commutator to which the defective leads are attached.

To determine an open circuit in an armature, apply a low voltage from a battery or a dynamo operating at reduced voltage, to the commutator at two opposite points. The surface of the commutator should be made perfectly clean and smooth. Place an ammeter in the circuit and see that the terminals leading the current into and out of the commutator are of such cross section that they will touch but one segment at a time when applied to the commutator. As the armature is rotated slowly, the open circuit will be indicated when the ammeter deflection drops to zero, showing that the winding to which the leads are attached is completely open-circuited.

SHORT CIRCUITS

The presence of a short circuit in the armature, commutator or fields is always indicated by faulty operation of the unit, requiring its immediate removal from service. If the short circuit occurs in the armature or commutator during operation, the exact spot or coil can generally be located by noting the point of high temperature, or blackening and charring. Short circuits in field spools are evidenced by a decrease in the voltage of a generator or an increase in the speed of a motor. Unlike the armature coils, the field coils, if short circuited, in most cases operate cooler than under normal conditions since a percentage of the exciting current does not pass around the total number of turns thus reducing the heat loss.

The magnetic strength of a field coil having a large part of its turns short circuited, will be much weaker than that of a companion coil with normal turns; consequently, a bar of iron held midway between the two adjacent spools will be pulled toward the stronger pole. It should be remembered that a double ground affecting any part of the electric circuit is equivalent to a short circuit.

A short circuit in an armature or field coil when evidenced in operation, is tested for by the drop of potential method. In rewinding an armature, it is well to test the coils for short circuits before connecting them to the commutator. Field or armature coils showing a reading approximately 10 per cent. below the average in the drop of potential method indicate a short circuit. A test for a short circuit in the commutator is made by means of the insulation resistance or magneto test.

SATURATION

In order to ascertain the characteristics of the magnetic circuit, a test known as "saturation" is made. The characteristic curve may be obtained by either of the following methods; "generator saturation" and "motor saturation."

The test usually made is "generator saturation." To obtain a saturation curve by this method, the machine is driven as a generator, preferably at constant speed. If, however, a set of readings is known for one speed, they can be obtained for any other by direct proportion. Hence a saturation curve taken at any constant speed at once gives the saturation curve at any other speed. The brushes of direct current machines should always be set on the neutral point when taking a no-load saturation.

The usual method of taking a generator saturation curve is to hold the speed constant, and then increase the field current step by step until at least 125 per cent., of the normal voltage of the machine is reached, taking readings at each step simultaneously, of volts armature, volts field, and amperes field. After reaching the maximum value of the field current, without opening the field, reduce the current gradually in four or five steps, and again take readings to determine the value of the residual magnetism at various points along the curve. Special care should be taken to insure accurate readings at and above normal voltage, since with alternating current generators, this is the portion of the curve used for calculating the regulation under load. Whenever saturation curves are taken, a record of the air gap from iron to iron should be made upon the record sheet, together with the armature and field specifications.

When it is inconvenient or impossible to drive the machine as a generator, a "motor saturation" may be made. In this case, the machine is operated as a free running motor. The driving power must be furnished from a variable voltage circuit. A certain voltage is impressed upon the armature and the motor field weakened or increased in the case of direct current machines to give normal speed, and a record made of the volts armature, amperes armature, amperes field, and speed. The starting voltage should be at least 50 per cent. lower than the normal voltage of the apparatus. The applied voltage at the armature should be increased step by step to a point 25 per cent. above normal value, and the field increased correspondingly to keep the speed constant, the same readings being recorded at the various steps as before. Readings should also be taken at three or four points, as the impressed voltage and field current are lowered to approximately the value at the beginning of the test.

Care should be taken when testing direct current apparatus, as unstable electrical conditions may develop, and excessive speeds result. The circuit breaker in the armature circuit of the motor driving the machine must, therefore, be accessible to the tester reading the speed.

ADJUSTMENT OF COMMUTATING FIELD

Some generators are designed to operate with full commutating field, and the strength of the field is adjusted by changing the commutating pole air gap. Shunts are provided for the commutating field of other machines, and its strength is adjusted by shunting more or less current; the air gap of the commutating poles being ordinarily left the same, although a combined adjustment of air gap and shunt sometimes gives the best commutation.

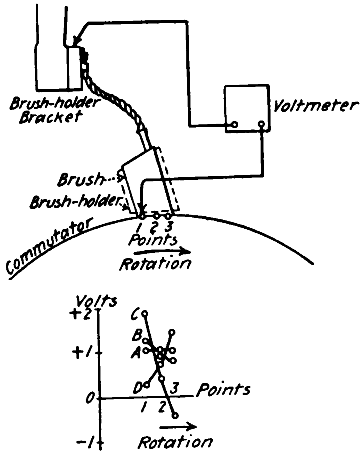


FIG. 102.—Commutating field adjustment by current distribution in the brush.

The commutating fields of all generators are adjusted at the factory, either by loading the individual machines, or by giving them the same adjustment as a duplicate machine which has been loaded. In most cases the factory adjustment, if not disturbed during shipment, will give satisfactory commutation, but it may be necessary to make a final adjustment after the machine is running under operating conditions in order to obtain the best commutation.

A very good indication of the proper adjustment of the commutating field may be obtained by taking readings of "current distribution" in the brush by drop from pigtail to commutator as in Figure 102. A direct current voltmeter with a 5 volt-scale should be used, one lead being held on the brush pigtail, or the brush holder bracket, and the other being held on the commutator at various points along the side of the brush. The voltage drop at any point is an indication of the current density in the brush at that point, and the curve formed by all the points indicates roughly the distribution of current across the face of the brush, and is termed the "current distribution curve." An absolutely uniform distribution of current gives a horizontal line, curve *A*, which is the ideal condition for collecting the maximum current from the commutator, but owing to several factors entering into the commutation process, this condition is seldom realized in practice except during heavy overloads on certain types of generators. The average form of current distribution curve obtained at normal load and with the best commutation is that of curve *B*, sloping slightly downward in the direction of rotation. In the case of some low voltage machines equipped with graphite brushes, the curve slopes even more rapidly in the same direction.

If the full load current distribution curve corresponds closely to curve *B*, the adjustment of the commutating field is approximately correct. Any further adjustment must be made by trial, strengthening or weakening the field by small steps and observing the effect on commutation, all other conditions remaining the same.

If on the other hand the curve resembles curve *C*, sloping rapidly in the direction of rotation, and perhaps crossing the zero line, the commutating field is too strong, and if it resembles curve *D*, sloping upward with rotation, the field is too weak, or perhaps reversed. The commutating pole air gap should be adjusted, or if a shunt is provided, grids should be removed or added, until the current distribution curve at full load resembles curve *B* and the final adjustment has been reached by trial for the best apparent commutation.

COMMUTATION

In commutating pole generators, commutation is affected by certain mechanical adjustments and refinements as well as by the adjustment of the commutating poles. When good commutation cannot be obtained by adjusting the commutating field, these mechanical features should be gone over thoroughly, trying the commutation after any change is made and noting the effect produced.

Go over all contacts and make certain that none are loose.

Check the connections and make certain that the commutating field or any part of it is not reversed, and that one or more of the main spools are not reversed.

Check the brush spacing and alignment both with paper tape, and by the commutator mica, revolving the armature to two or three positions to detect errors due to variation in the thickness of bars or mica. The brush spacing should always be checked with reference to the trailing side of the brush, that is, the side on which the commutator bars leave, and on which sparking usually appears. Machines of certain designs are very sensitive to brush spacing, and a variation of over 1/16 of an inch should be corrected. In general, the more accurate the brush spacing, the more uniformly good will be the commutation.

Check the mechanical neutral, and try shifting the brushes each way from neutral. Very often a slight shift is advantageous.

Go over the brushes and see that they move freely in the holders, and that the pigtails do not interfere with any part of the rigging. Check the pressure and see that the fit is good. Look for burning or roughness of the contact surfaces.

Inspect the surface of the commutator and wipe off any blackening. If it is rough or eccentric, causing the brushes to chatter or move in the holders, it should be ground or stoned, and perhaps turned. Directions for doing this work are given in Chapter IV.

Check the centering of the commutating poles between the main poles, and check both the main and commutating pole air gap.

These adjustments for commutation should be supervised if possible by someone who underatands the theory and operation of direct current machines, and is experienced in adjusting them.

VOLTAGE REGULATION

The voltage regulation of a self excited shunt wound generator equipped with commutating poles and pole face windings can be tested by first bringing the voltage to the normal rated value at no load; then, bringing the machine up to full load by quarter load increments, without adjusting the field rheostat, note the voltage reading at each point. These results if plotted in the form of a curve whose ordinates are volts and loads will give the voltage characteristic of the machine showing the voltage obtainable at all loads without field adjustment. A separately excited shunt wound generator will operate with much less droop in the voltage curve than that of self excited machines. If commutation permits, the droop in the curve of either type may be decreased by shifting the brushes backward against rotation, where the unit is designed with commutating poles. Generators without commutating poles will operate with the least amount of droop if the brushes are placed as near as possible to the no load neutral.

A test of the voltage regulation of a self excited shunt wound generator not equipped with commutating poles or pole face windings cannot be made by the method outlined above since the armature reaction is not compensated for and the voltage will drop to practically zero before the normal load point is reached. In such instances, the following test should be employed to secure the necessary data for plotting the regulation curve. A reading should be taken first at the no load normal voltage. Without changing the rheostat, one-quarter load should be thrown on and a reading taken of amperes armature, volts armature, amperes field and volts field. Holding one-quarter load, the voltage should be brought up to normal and the same readings taken. The load should now be increased to one-half full load and with the rheostat in the same position, similar readings repeated. This test is repeated for three-quarter and full load. With full load on the machine the voltage should be brought up to normal. With the field rheostat in this position, the load is then taken off the machine and the rise in voltage observed. All of these entries should be made on a record sheet and a curve plotted with amperes armature as abscissæ and volts as ordinates. If the voltage should drop to zero when one-quarter load is put on the machine, the load should be applied in smaller increments. The speed should always be kept constant throughout the test.

The voltage regulation of compound wound generators is adjusted at the no load and full load points. The regulation between these points can be obtained by loading the generator with successive increments of one-quarter load each and plotting a curve with the resulting data, providing no adjustment of the shunt field rheostat is made. Tests should be made while the load is being increased and decreased. A departure from a straight line drawn between the no load and full load points indicates the voltage regulation of the generator. The departure or hump between the curve and the straight line will be found to vary in amount with the different types of machines running from 2 to 10 per cent. Flat compounded machines show less hump than over compounded units. The shape of the compounding curve is typical of each machine and practically no change can be made in the unit to alter its curve.

SPEED REGULATION

Speed regulation is important in the operation of direct current motors. In all cases adjustments should be made hot, that is, with the machine at its normal operating temperature. The voltage must be held at a constant value throughout the test for both shunt and compound motors. Data for plotting the speed regulation curve is obtained by loading the machine beginning at no load and advancing to full load in small increments, recording carefully the speeds at the intermediate points. The curve of shunt wound motors without commutating poles will show a drooping characteristic while similar machines equipped with commutating poles will operate at a more constant speed from no load to full load and in some cases where high armature reaction is present, the speed will rise as the load is applied. A speed variation from the normal rating of 4 per cent. is considered allowable in good practice but the regulation should not exceed 6 per cent. except in special cases. Variable speed motors with wide speed ranges such as 2 to 1 or even 3 to 1,when shunt wound, tend to have a rising speed characteristic which may be remedied by increasing the air gap or shifting the brushes forward in the direction of rotation, if commutation will permit. Where frequent reversals are required in the operation of such motors, the brushes must be placed and kept on the electrical neutral which is determined by operating the motor at no load and full load under constant voltage, shifting the brushes until a point is found where the speed is the same in each direction.

The speed of a compound wound motor can be adjusted at will by changing the strength of the series field, weakening for flat or constant speed and strengthening for drooping speed. A series wound motor has a speed for every condition of load which may be changed by shunting the series field to give the required value. When speeding up motors with increasing load, the brushes must never be shifted far enough as to produce sufficient armature reaction to weaken the field. Careless shifting of the brushes under load has sometimes caused runaways.

HEAT RUNS

When it is desired to make a check on the guarantee values in regard to temperatures after installation or to determine the maximum loads which may be carried without exceeding safe temperature limits, heat runs may be conducted under the following conditions. Load the generator or motor to its normal rated capacity in voltage and amperage. This can be done by using the machine's natural load in its working circuit if the character of the load is constant over a sufficient period of time to allow all parts of the machine to reach the maximum temperature. Where the load is fluctuating, a generator may be artificially loaded by the insertion of a water box or by the "feeding back" method, described at the end of this article. Constant load on a motor may be obtained by the use of a brake.

The time required for reaching a constant temperature varies in proportion to the size of the unit. From three to four hours continuous run will suffice for units whose rating does not exceed three hundred kilowatts while above this value it is necessary to continue the run from five to eight hours. Thermometers should be attached to all stationary parts such as field coils, connections, bearings, magnet frame and where possible, at the outlets of the armature ventilating ducts. It is customary to attach these thermometers by means of putty or cord covering in either case the bulb of the thermometer to exclude the air. When the thermometers register a constant temperature for at least thirty minutes, it is safe to assume that the revolving parts have reached the maximum temperature and that the unit may be stopped. Additional thermometers should be immediately placed on the armature coils, end windings, soldered clips, equalizer rings, laminations and the commutator bars, and their temperatures recorded.

Should the test under normal conditions indicate a cool running machine, the rating may be increased and the heat run repeated providing the commutation will permit. The temperature limits for the various classes of insulation have already been given on page 187. In making a check on the overload temperature guarantees, it is necessary to first conduct the test under normal conditions. When constant temperatures have been reached and without shutting down, the overload should be applied for the specified time, after which the unit should be shut down and all temperatures taken.

The water box method previously referred to in this article, as the name implies, consists in driving the machine either by a motor or engine and loading it with a water rheostat or "box." See Figure 103. This method entails considerable expense, since all the power generated is lost. To obviate this loss and reduce the cost of testing, the "Feeding Back" method is used when possible, especially in the case of large direct current machines or motor generator sets.

In this method the total machine losses are supplied either mechanically or electrically from an external source. In the mechanical loss supply method, two machines of the same size and voltage should be belted or direct connected together and driven by a machine large enough to carry the loss of the set. Connections are made as shown in Fig. 104. If the machines have series fields, each field should be connected to boost its shunt winding which requires that the machine, to operate as a motor must have its series field reversed and accumulatively compounded. Both machines should then be run up as generators and thrown together by closing the switch between them when the voltage across it is zero. The field of the machine to act as motor should then be weakened, which throws load on both machines. The speed is held constant by the loss supply motor. After running at the proper load

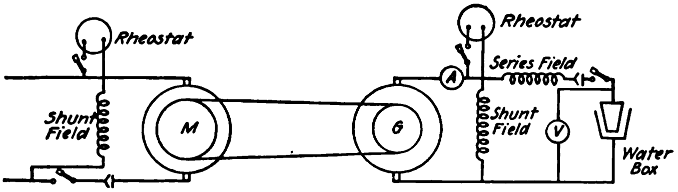


FIG. 103.—Sketch showing connections for loading a D.C. generator on a water box.

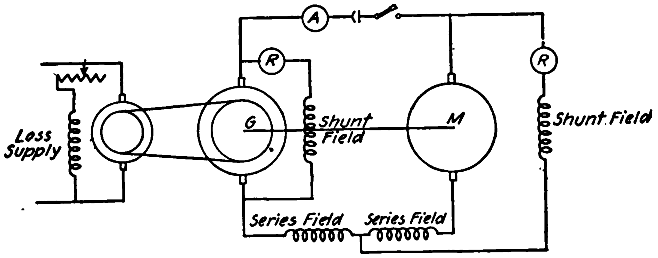


FIG. 104.—Sketch showing connections for mechanical loss supply pump back.

for the specified time, the heat run should be taken off and tests finished according to standard requirements.

If the machines are motors, the same connections should be made and the machines thrown together as before. The voltage of the system must be held by the machine running as a generator. The only correct way of obtaining load is by changing the speed of the set, the brushes having previously been set in the running position. Usually the speed will have to be decreased and the difference between full load and no load speed will be the normal drop in speed for the motors. Cases have occurred where the speed of the motor, due to armature reaction, increased during the load. In pumping back, this fact is shown by the motor taking an overload at no load speed in which case the speed of the loss supply must be increased.

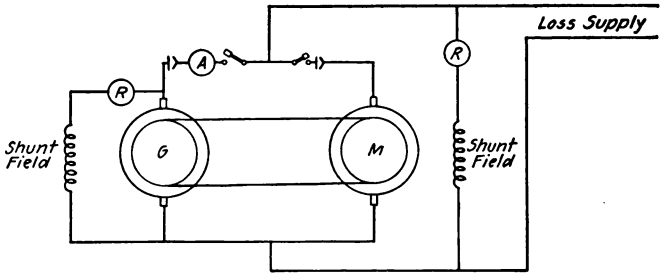


Fig. 105.—Sketch showing connections for electrical loss supply pump back.

In the method of electrical loss supply, two machines are direct connected or belted together and the losses supplied electrically. Should two shunt motors be tested by this method, one machine should be run at normal voltage, current, speed and full field; the other motor should be run as a generator with a little higher current and slightly stronger field than it would have under normal conditions. The fields of the generator may have to be connected in multiple. Connections should be made as in Fig. 105. The motor should be started first from the electrical loss supply circuit and its brushes shifted for commutation and speed. After exciting the field of the generator and adjusting the voltage between the machines to zero, the circuit is closed. The machines are loaded by increasing the field current of the generator.

The brushes must always be shifted carefully while the machines are under load, for a slight change in shift will at once change the load. After the heat run has been finished and all motor readings taken, the wiring should be changed and the motor readings taken on the machine which ran as a generator.

When compound wound generators are being tested by this method, the series field of the motor must be included or the load will be unstable.

Another method of "Feeding Back," often used, is to run the entire load back on the main supply circuit from which the motor driving the generator in test is operated. If the main supply circuit is likely to vary in voltage, it may be necessary to insert resistances between the generator and supply. It sometimes happens that the no load voltage of the generator is below that of the supply. As changing the line resistances will have no effect at no load, the generator voltage must be increased until it is equal to that of the main supply circuit. Having previously calculated the full load field current from the no-load current, and the ratio of compounding voltages, the machines are thrown together and full load put on the generator by cutting out the variable resistance.

CORE LOSS

Three methods are used to measure the core losses on rotating direct-current apparatus. They are known as follows: "Running light core loss," "Belted core loss," and "Deceleration core loss." The "running light" test is made for all direct-current generators and motors which are given a running test. It is occasionally, though not frequently, employed with alternating-current synchronous apparatus.

The following conditions must be obtained with direct-current apparatus in order to give satisfactory results: the brushes must be shifted on the commutator to the no-load neutral point; they must have their normal tension and the commutator must be clean, so that the normal operating commutator and brush friction values are obtained. This test, wherever possible, should be made after all the others have been finished, in order to have a glossy commutator with its surface in good operating condition. The driving power should be supplied from a variable voltage circuit that is not subject to sudden fluctuation. Since the power input required to drive the machine running free as motor must be obtained, its value must not be read when the rotating parts are either accelerating or decelerating. A steady voltage must be kept on the armature and the field current must have a constant value.

When "running light" tests are made on direct-current generators, the observations must be made with full load field flux. The potential applied to the armature must be equal to the normal rated voltage of the generator increased by the *IR* drop in the armature at full load. With this voltage impressed, the field current is varied until normal speed is obtained, when careful readings must be made of armature current, armature voltage, field current, field voltage and speed.

If the machine in test is a direct-current motor, the voltage applied to the armature should be equal to the normal rated voltage of the motor, less the *IR* drop in the armature under full load. The field current is then adjusted to give normal speed and electrical and speed readings taken, as oultined above for direct-current generators.

The power supplied to machines running free will equal that absorbed in bearing friction, brush friction, windage, and core loss, when the armature I^2R losses have been subtracted.

In making records of these tests, the testing record should show clearly whether the running light current consists of the armature current plus the shunt field current, or whether it is the armature current alone. To check this point, open the armature circuit with the shunt field circuit closed, and note whether any current is indicated, on the ammeter, reading the power supplied. If no current is indicated, the reading indicates the armature current alone, otherwise, the running current is equal to the sum of the armature and field currents. To obtain "running light" core loss tests, only a single field winding must be used for excitation; this must be a shunt field winding.

The "belted core loss" method separates the core loss from the bearing friction, brush friction, and windage. A small direct-current motor is used to drive the machine under test as a generator at its rated speed. A belt drive between these machines is most commonly used. However, wherever great accuracy or a high speed is necessary, direct driving by a coupling is often used.

The driving motor for this test must be carefully chosen. It must be operated through the range of load required for the core loss test with good commutation and with a fixed setting of the brushes. Ordinarily a safe rule to follow is that the motor should be approximately 10 per cent. of the capacity of the machine under test. The maximum load which this motor should carry with the heaviest field on the machine under test should not exceed 50 per cent. of its normal rated capacity. The driving motor should be operated as nearly as possible at its rated speed and field strength. The brushes should be carefully set at the best position for good commutation at all the loads required by the test. The commutator surface should be in first class condition.

The weight and width of the belt must be selected to give minimum loss. When testing motor-generator sets, rotary converters, and apparatus which does not use belts, the tension of the belt must be kept as low as practicable, so that the bearing friction is not increased due to the belt pull. Endless belts should be used in preference to laced belts.

The driving motor must be wired so that readings may be taken of amperes armature, volts armature, amperes field, and speed. A reading should be taken on the motor corresponding to normal speed of the machine under test. The machine under test should be wired with its field separately excited and provision made for reading amperes field, volts field, and volts armature. Previous to starting the test, careful resistance measurements of the armature of the driving motor, must be made.

The test is then carried out, as follows: The field of the driving motor is adjusted to about normal value and excited from a source of constant voltage so that its value may be held constant throughout the test. The speed of the driving motor is regulated by varying the voltage applied to its armature terminals. First, run the driving motor and the machine under test a sufficient length of time to allow the friction to reach a constant value. This will be obtained when the input on the driving motor becomes constant when driving the machine under test without any field excitation. Careful readings should then be taken first of the input to the driving motor with the machine under test unexcited and all brushes down on the commutator. Following this reading, a second should be taken with all brushes raised from the commutator of the machine under test. The difference between these two sets of readings will give the brush friction on the machine receiving the test. Starting with the zero field on the machine under test, observations of the input to the driving motor should be made at various values of the field up to that which will give 125 per cent. normal load voltage. Correcting the motor input at these various field strengths by taking out the I^2R loss in the armature of the driving motor, and subtracting the power input to the driving motor with zero field, the core loss is left corresponding to the various field strengths.

In order to insure constancy of friction losses during the entire test, the readings of the motor input with zero field should be repeated at least three times during the progress of the test; namely, at the beginning, again near the middle point of the curve, and lastly at the end of the test. Readings should also be taken at the end of the test with normal voltage, field current and with brushes raised from the commutator, to compare with the reading in which the same field was used with the brushes resting on the commutator, and with the set of readings giving the brush friction.

These values should be checked to see that they are consistent. To check the results of the core loss as the test proceeds, the power input to the driving motor required by the core loss at a given excitation should be plotted against volts armature generated. If a satisfactory curve is obtained, the driving motor can be unbelted and a running free reading taken upon it, holding the same amperes field as were used during the test. The bearing friction and windage losses of the machine under test can be separated.

For a successful core loss test, all readings must be made at absolutely constant speed, when the rotating parts are neither accelerating nor decelerating. All field currents must be held constant No pulsation or sudden variations must occur in the armature current of the driving motor which might vitiate the power readings. On series motors, core loss tests should be taken at several different speeds covering the range of the speed curve.

EFFICIENCIES

Efficiency tests, if required should be made whenever possible on the manufacturer's test floor, as the inaccuracies of station meters and the lack of facilities for measuring the resistances of circuits make it almost impossible to get accurate data in practice. Efficiencies taken by the input-output method require a very careful calibration of all instruments and in making the test all meters must be read at the same instant. It will be found that the readings taken will vary over wide ranges and for this reason it is necessary to check each point at least ten times and then use the average value obtained. Engine driven units requiring the making of indicator cards to determine horsepower input furnish another source of inaccuracy because of the difficulty of getting the input and output readings simultaneously. It is practically impossible to determine the exact efficiency of belted, geared or water wheel driven machines after installation.

On the test floor the exact electrical losses are determined by careful measurements of the load values, resistances of the various circuits, friction, windage and core losses. These losses are added to the machine's output measured on accurately calibrated instruments. The efficiency of a generator is then calculated by dividing the output by the input and that of a motor is obtained by dividing the product of the volts times the amperes input, minus the losses, by the volts times the amperes input.

BEARING INSULATION

In testing the insulation between the bearing pedestal and the base, it should be borne in mind that this insulation is not required to resist high voltages to prevent the flow of current through the shaft. For this reason in testing, a voltage of 125 volts or under should be applied across the insulation which is suspected of being defective. A ground or a partial ground between the base and the bearing pedestal will be shown by a voltmeter in series with the voltage supply, one of whose terminals is connected to the base and the other to the pedestal. In making this test, the path of the current through the shaft and the other pedestal or other mechanical parts, back through the base must be broken up. This is usually accomplished by slightly raising the armature and fitting a support which permits the bearing and oil ring to be separated from the shaft, thus interrupting the mechanical path.

STARTING TEST

A starting test on a motor is made to determine whether or not the lights or other apparatus operating in the same circuit are affected when the motor is thrown on the line. The test may be made as follows: Place an ammeter in series with the motor line, the instrument having a sufficient capacity to take the maximum load required. The line voltage should be noted and compared with the voltage rating on the nameplate. Close the shunt field circuit as in usual practice and place the starting switch on the first point. The maximum swing of current should be read on the ammeter and also the drop in voltage. As soon as the current reaches a constant value, the starting box is moved to the second point again recording the current and voltage. This process is continued over the entire range of resistance until the motor is running directly on the line, that is, with all resistance cut out. Should it be found that the starting of the motor is responsible for a line disturbance affecting the other units or lights, a starting box with a greater number of points should be installed to relieve the trouble by reducing the amount of current required in each step.

HIGH POTENTIAL TESTS

All direct current machines are given a high potential test before testing, using an alternating current voltage which is applied for one minute for all standard work. The voltage is varied to suit the voltage of the machine and the type of insulation with which it is fitted. Standard practice requires a test of double the working voltage plus one thousand but fifteen hundred volts is the minimum value used for new machines. Rebuilt or repaired direct current units should not be subjected to voltages of more than one-half of the values given due to the aging and depreciation of the insulation in service. The usual insulation test by use of a voltmeter in series with the power circuit is sufficient to indicate a weakening of the insulation without applying the high potential test which may result in a complete failure of the insulation. No machine should be subjected to a high potential test unless it has been previously cleaned thoroughly and dried out if necessary.

REPAIRS

Replacing Armature Coils—Replacing Commutator Segments—Field Coils—Damaged Insulation—Equalizer Rings—Reconnecting An Armature—Broken Commutator Bolts—Short Circuited Commutator Segments—Loose Cores and Defective Laminations—Wedges—Rebabbitting Bearings—Drying Out.

REPLACING ARMATURE COILS

In addition to ordering the required number of new coils and wedges, slot insulation (if any) and binding band material should be ordered. Make a note of the location, number of turns, and method of fastening the old bands before cutting them off.

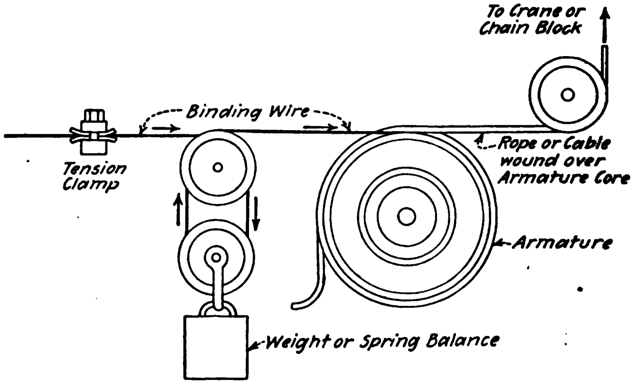


Fig. 106.—Winding armature binding bands under tension.

Always drive the old wedges outward from the center and drive the new ones toward the center from each end, in order to avoid wearing the edges any more than necessary. In soldering, be careful not to drop pieces of solder into the armature or into the commutator. Do not use an acid that will attack the copper, or the insulation (rosin dissolved in alcohol is the best flux for electrical joints.) In winding on the new binding bands, the tension should be measured as the wire goes on. Figure 106 shows a simple method of measuring the tension, and the following table gives the proper tension for various sizes of wire for one and two layer bands.

MINIMUM TENSION (IN LB.) ON STEEL BINDING WIRE

Size wire	One layer	Two layers	
		Bottom layer	Top layer
0.057	180 to 220		
0.072	400 to 450	450	400
0.091	500 to 550	550	475
0.102	500 to 600	600	500

The pulleys must not be less than 8 inches in diameter and the weight must be twice the desired tension in the wire. A cubic foot of cast iron weighs 450 lb. When an armature has been completely rewound, it must be banded temporarily up to the full tension and baked, before the final bands are put on. Unless the binding bands are given the proper tension, so that

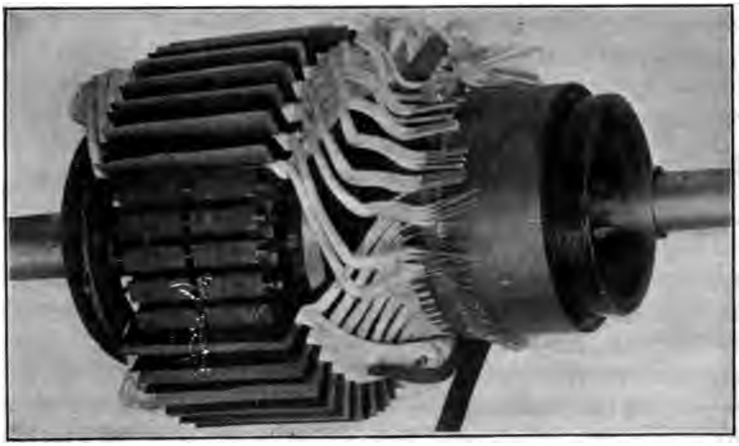


FIG. 107.—Armature partly wound showing insulation and method of connecting.

they will remain tight, the windings will chafe and finally break down.

In removing a defective armature coil, it is necessary to disturb the conductors over one or more pole pitches and care must be taken to prevent damage to the insulation where it is necessary to bend or spring the coils during removal. Before the conductors are replaced they should be given a thorough coating of insulating varnish to close all breaks or cracks. Since full difference of potential occurs between the upper and lower conductors in the slot and between the end windings close to the end of the core, the insulation at these points should be made as perfect as possible when new coils are installed or when an armature is rewound. Slot armor, whether moulded on the bars or used as a trough in the slot, should be closely examined for indications of cutting caused by loose laminations. Flange insulation under the end windings should be of uniform thickness, ironed in place under pressure and heat to form a solid bed supporting the conductors when the pressure of the binding bands is brought to bear.

REPLACING COMMUTATOR SEGMENTS

When it is necessary to replace a commutator segment in service, first cut or unsolder the connection of the faulty bar to the armature. Wrap the commutator circumferentially with sufficient turns of ordinary binding wire or apply special steel rings fitted with sectional tightening and clamping blocks, to insure the integrity of the commutator while the front clamp ring is removed. Then remove the clamping ring bolts and withdraw the clamping ring on the outer end of the commutator. If this ring is sectional, remove only the section which the defective bar affects. Loosen and slide out the faulty segment and replace with a new one; where necessary insert new side mica. Repair commutator segments are usually shipped with the V notch unfinished, which must be filed to an accurate fit, using one of the old bars as a templet. Too much care cannot be used in fitting the new bars, as a poor fit may cause considerable trouble in getting the commutator settled and smooth. Damaged bed or ring mica should be built up to a uniform thickness, using thin sheets of mica. The front cone mica can be replaced without disturbing the commutator, but replacement of the bed mica demands a complete rebuilding of the commutator. In replacing the cone mica on the inner ring, the commutator should be disconnected from the armature windings and pressed off the shaft or spider in order to expose the bolts and clamping ring. Commutators constructed with through bolts should be handled with great care to prevent the back end from becoming displaced by the removal of the bolts during repairs. When shrink rings are fitted, in addition to the clamping rings, it is necessary to heat the shrink ring and remove the ring together with its insulation before a bar can be inserted. After replacing bars, the commutator bolts must not be tightened to such an extent as to distort the clamping rings, break the mica insulation, or spring and break the copper segments. It is always necessary to turn or grind the commutator to insure a smooth running surface where a replacement of segments has been made.

When a commutator must be rebuilt, the correct number of segments and pieces of mica are assembled in the form of a circle, shellacing the mica strips as they are placed between the bars. The segments are made to conform to a circular shape by placing them in an assembly ring adjusted by screwing segmental blocks in or out. The segments held firmly in the ring are then placed in a lathe and the V notches cut out at each end. Bed mica is fitted around the spider and cone mica on each clamping ring. The bars are then clamped tightly and evenly between the two rings making sure that the center line of the bars is parallel with the center line of the machine.

After the cone or bed mica has been replaced or the commutator completely rebuilt, it must be seasoned or baked to remove the solvents from the mica insulation and thus prevent shrinkage and loosening of the commutator in service. This may be accomplished by placing the entire commutator in an oven and heating for from ten to twenty hours, depending upon the size of the commutator, at a temperature of from 150 degrees to 200 degrees Centigrade. Vent holes should be drilled to facilitate the easy exit of the gases from the commutator as described under "Drying out."

FIELD COILS

A defective field coil may be removed from a direct current machine for repairs or replacement by withdrawing the bolts holding the pole to the frame structure or by removing the bolts holding the pole faces to the main pole cores. After the connection strips are disconnected, the pole piece with the spool in place is carried along the armature to a position where the core may be slid out without disturbing the armature. It is well to place a strip of cardboard, fibre or padding in the air gap at the point where the pole is to be moved in order to protect the armature. Where it is necessary to unbolt the pole face, the armature must be first withdrawn or the magnet frame separated if it is constructed in two halves.

If the coil is damaged beyond repair it should be replaced with a new coil or rewound. The insulation on the spool body should be examined and replaced if damaged, punctured or rendered ineffective by age. New collars are substituted for those which have become split, warped or burned. This is done by straightening out the sheet iron body and constructing new collars of laminated maple wood or fibre. New shunt wire may be rewound where short circuits between turns have developed but the series turns usually require simply a renewal of the insulation unless the copper has been badly burned. Mummified coils have no collars or spool bodies and are generally mounted directly on the core necessitating a heavy outside insulation. Commutating fields are sometimes wound upon the insulated core held in place by insulated bolts and washers but are most always mounted on spools in a similar manner to that employed on the main field poles. Pole face or compensating windings are repaired and replaced in the same way as armature coils.

DAMAGED INSULATION

Damaged insulation should be immediately repaired as soon as it is noticed, using wherever possible materials similar to those originally employed. The following insulating materials are recommended for use in making repairs: shellac, insulating varnish, linseed oil, japan, enamel, adhesive tape, cotton, silk, cambric, rubber, fibre, mica, glass, slate and porcelain. A standard insulating varnish having a mineral base can be procured from any electrical supply house for use in making repairs but in emergencies shellac, linseed oil or japan will serve the purpose well.

Small cuts or breaks in new insulation should be sealed by painting with insulating varnish and taping, where space permits, with treated tape. Charred or burned insulation on grounded or short circuited coils must be scraped clean to the copper to remove all traces of carbon and then submitted to the insulating varnish and tape treatment. The tape to be applied should be the same as that originally used and heat resisting or fireproof insulation such as mica must not be replaced by treated cloth or cambric except in emergency situations. It is usually more economical and far more reliable in cases of badly damaged insulation, to replace the defective parts with new ones rather than to attempt a repair.

Due to a continued high temperature or a very long period of use, the insulation may have become dried out or lost its life. Cracking and peeling will occur upon slight disturbances, vibration or handling, and a treatment must be given to insure against a complete breakdown The armature and field coils should be raised to a temperature of from 100 degrees to 150 degrees Centigrade by loading or heating in an oven and then dipped in a bath of insulating varnish and allowed to cool off slowly. This process should be repeated until the surface of the coils presents a solid appearance showing that all of the pores and cracks have been completely filled. A thorough baking in an oven should then be given at a temperature of 100 degrees Centigrade, unless the operating value exceeds this value in which case the temperature should be raised to a point slightly above the maximum running temperature to prevent a softening and running out of the insulating material in service. The baking should be continued for from 10 to 15 hours, that is, until all solvents have been completely vaporized. The above treatment should be given to machines whose service requires them to operate under moist conditions where no provision has been made for such operation in their design. In addition to dipping and baking the armature and fields it is well to spray the metal parts such as the pole pieces, the inside of the frame and the brush holder yoke, with air drying japan or varnish to exclude moisture and thus prevent rusting. Small bolts under one-half an inch in diameter, springs, nuts and washers should be sherardized or copper plated and all bushings and insulating washers dipped in hot linseed or varnish to prevent warping and distortion during operation.

Side mica on the commutator, burned, charred or honeycombed with carbonized paths must be replaced by sheets of new mica if the burning has extended to a depth of more than one-half inch. Temporary repairs can be made by cutting away the carbonized mica and removing all burnt particles and filling the slot with commutator compound. If it is impossible to secure this compound already prepared for use or if the emergency demands immediate action, a paste made of water glass and Plaster of Paris may be applied after the burned particles have been thoroughly scraped out.

EQUALIZER RINGS

Equalizer rings connecting equal potential points on multiple wound armatures are mounted either at the back or coupling end, or at the commutator end. In the latter case, the connections are made directly to the risers or leads. Repairs to defective equalizers consist in a replacement of burnt or damaged conductors, repairs to insulation and perfecting mechanical joints. Faulty rings should be disconnected from the armature coils at either end and the insulation completely replaced over the entire length of the damaged portion. Where the equalizer rings and leads are separated by air spaces, it is unnecessary to remove the entire number during replacement, but on an armature which is equalized at every slot, having the rings mounted so that they fit one in the other, it is advisable to remove all of the rings after first loosening the holding brackets or cords. The damaged insulation or defective rings should be replaced and the entire group blown out with compressed air. The rings are then reassembled, corded and fitted to the machine. Where an oven is available together with a tank of sufficient size to permit the assembled rings to be dipped as a unit, a thorough filling with a good insulating varnish can be applied after first heating the set of rings and then finally drying by baking in the oven to a temperature of from 100 degrees to 150 degrees Centigrade.

Additional equalizers are fitted on an armature when trouble has developed due to too few equalizers, without disturbing the rings already in place, by inserting the new rings either above or below the old ones and connecting them to the proper armature end clips. The new spacing is determined from the old spacing, counting the number of end clips between connections to locate the new equal potential points. Wherever possible a complete set of equalizers should be installed with a connection for at least each slot in the armature and perferably, for each end clip. This requires discarding entirely the old equalizers and making up an involute type which may be mounted horizontally or vertically on the armature spider or special ring provided for the purpose. It should be remembered that a machine with an odd number of slots, that is, a number not divisible by the number of poles, cannot be equalized. Taps for the first equalizer ring should be located by marking the armature end clip directly under the center of all poles of like polarity and joining these clips together with a copper connection. The other rings will follow in the regular order, after the proper relation of the first ring is established. Armatures having four, six, eight or more conductors per slot may present a mechanically impossible problem to equalize all of the end clips and in such cases care must be taken to select for connections the end clips in the same relation in all of the slots around the armature.

RECONNECTING AN ARMATURE

After an armature has been rewound, the wiring diagram of the machine should be consulted in order to determine the proper connection to the commutator. If the wiring diagram is unavailable, a sketch of the connections should be made before the old winding is stripped and it is also advisable to mark one or more slots and one or more corresponding commutator segments as a starting point for connecting the new coils.

Armatures designed for 600 or 250 volt service may be reconnected for 300 or 125 volt service, providing that the number of conductors per slot is such that two conductors may be placed in multiple. For example, reconnection for a lower voltage is possible where four or eight conductors per slot are found, since a conversion to two or four conductors can be effected by connecting the bars in multiple at the end clips or at the commutator. Reconnection for half voltage cannot be made where six or ten conductors per slot are fitted since connecting pairs in multiple will still leave an odd conductor. The commutator segments must also be placed in multiple, which may be done by soldering the end clips together at the risers or by soldering a copper strap at the end of each pair of bars to be paralleled. The current carrying capacity of the armature conductors after reconnection will be doubled, while the generated voltage is reduced to one-half its former value. Operation under the double current depends upon the brush capacity, which is the usual limiting feature. The new kilowatt rating must be based upon the brush and commutator capacity. Attempts to increase the width of the brush to accommodate the increased current are generally impractical due to too much overlap of the segments. When the current is doubled, the field connections must be so arranged as to put the two halves of the series and commutating fields in multiple in order to obtain the same field strength as before. New shunts for adjustment of the series and commutating fields are required. Due to the reduction in voltage, the shunt fields must be connected with both halves in multiple, reducing the total resistance to one quarter of its value. A new shunt field rheostat must be installed to accommodate the doubled current although each half of the field receives the same amount as before.

An armature can be reconnected for double voltage if a number of conductors per slot, such as four or eight are employed, by connecting the adjacent conductors in each slot in series instead of multiple, but this requires a rebuilding of the commutator to double the number of its segments and new shunt, series and commutating field coils. Unless new shunt coils are furnished, a field rheostat must be installed to reduce the voltage across the field to one half of its value, entailing a great inefficiency. The insulation of the armature conductors and creepage surfaces must be sufficient to withstand the double voltage, which usually requires another change. For these reasons it is seldom advisable to reconnect a machine for a higher voltage.

BROKEN COMMUTATOR BOLTS

Broken commutator bolts should be replaced as outlined fully on page 169 by substituting a bolt of sufficient length to permit of considerable expansion. The drilling for the short bolt in the commutator should be continued until a depth is reached which permits the use of a bolt from two and one-half to three times the length of the original bolt. The new bolt should be "necked down" just above the threads for a distance equal to at least two diameters. The reduction in diameter or "necking down" should not bring the size of the bolt below the dimension at the bottom of the thread. Both ends of the commutator should be given this treatment even though the trouble may have developed in one end only. In case it is mechanically possible to drill the spider the entire length and use long through bolts, to hold both front and back clamping rings, it is advisable to adopt this arrangement. The through bolts should be reduced in diameter in the center over a space of from three to four diameters as mentioned above. The commutator bolts should be carefully and evenly tightened after replacement.

SHORT-CIRCUITED COMMUTATOR SEGMENT

The repair for a short-circuited commutator segment is described in Chapter VII on page 167.

LOOSE CORES AND DEFECTIVE LAMINATIONS

The repair for these failures has been outlined in Chapter VII on "Troubles and Their Remedies" on page 195.

WEDGES

Wedges cause trouble when improperly seasoned, due to shrinkage. In service they tend to loosen and fly out thus permitting the armature conductor to move in the slot and chafe its insulation, or even to fly out against the pole piece with the danger of wrecking the machine. Various materials are used in the manufacture of wedges such as fibre, brass, wood and steel. Of these, cross grained hard wood has given the best results. Since the wedges when driven into place are slightly reduced in size, it is inadvisable to make use of the same wedge when rewinding the armature, especially in the case of high speed armatures where a great strain is placed upon the wedges.

REBABBITTING BEARINGS

Before melting out the old babbitt, take particular note of the oil grooves and holes, and the beveling at the joint, making a sketch, if necessary, so that these features can be duplicated. A piece of pipe, or other metal cylinder of the proper size may be used for a mold, closing the openings between the shell and the mold at the ends, with felt or putty. When the new babbitt is cool, the two halves of the bearing should be put together, and bored or reamed to the proper size. The oil holes should be drilled out and the grooves bored or chipped. The shaft may be used as a mold, if necessary, wrapping a thin piece of paper around it to prevent sticking, and the bearing fitted by filing and scraping.

DRYING OUT

If a machine has not been exposed to rain or unusual dampness and has been set up in a dry operating station, no drying out will be necessary. If, on the other hand, a machine has been long exposed to the weather, or has been wet, or has been set up in a new station not warmed, or damp owing to fresh concrete or other causes, the following precautions should be taken.

A simple shunt machine should have its field opened and its armature short-circuited by a cable which will carry two or three times the normal armature current and which is also of sufficiently low resistance to constitute a "dead short-circuit." When a generator of standard design is driven at normal speed under such conditions, the residual magnetism will cause a circulating current to flow in the armature, its value being between normal full-load current and twice this amount, which is a good working value for drying out. Should it be found that the residual magnetism will not cause a sufficient current flow, the shunt field should be very weakly excited from some external source (the low field current necessary can be obtained either from a very low-voltage source direct or from an ordinary voltage source by inserting a high resistance in the field circuit). If severe sparking takes place at the commutator when operating under these conditions it can be minimized by giving the brushes a forward shift.

Ordinarily enough heated air will be thrown off the rotating armature to dry out the field. In case this proves to be insufficient, or only the field is damp, heat can be localized in the field winding while the machine is at rest by connecting the spool to an external source of excitation. From quarter to normal voltage should be applied, depending on the dampness of the spools.

It has been suggested that a machine can be dried out by applying alternating-current to the field winding while the armature is short-circuited. This method is open to the serious objection that the alternating flux will cause excessive heating in those parts of the magnetic circuit which are not laminated.

A commutating-pole machine that has no series field winding should be dried out in the same manner as described for a simple shunt machine. Care should be taken that the brushes are not back of the neutral but are slightly forward of it. The commutating-pole winding is to be wired in exact accordance with the standard diagram of connections for operation; and the short-circuit placed on the machine is to include the commutating-pole winding as well as the armature.

A compound machine should be dried out as described in the foregoing except that the series-field winding should be cut out of circuit entirely. The latter is a precaution to prevent the possibility of the machine building up as a series generator in case no external excitation is applied to the shunt field.

While the above instructions apply to all sizes of machines, where the unit is small and easily handled and where an oven is available, it may be more convenient to thoroughly dry out the machine by baking it in the oven at a temperature of from 100 to 150 degrees Centigrade, until the insulation resistance measures approximately 500,000 ohms. If, after an extended baking, this value cannot be obtained, it is an indication that moisture is pocketed in such a way that it cannot escape even though vaporized. This trouble is usually found to exist in the commutator at the clamping ring insulation or the body mica. As a remedy, vent holes, not exceeding one-half an inch in diameter, may be drilled in the rings or spider, or both, to allow the escape of all vapors. The drilled holes should be carefully plugged and sealed before operation is resumed to prevent the entrance of dirt, grease and foreign matter. In drilling the vent holes great care must be exercised to keep the drill from damaging the mica insulation. If possible, a drawing of the commutator should be obtained from the manufacturer to locate the vent holes to the best advantage.

CHAPTER IX

USEFUL DATA

SAFETY RULES—RESUSCITATION METHODS—STANDARD SIZES OF CABLES TO BE USED IN CONNECTION WITH D.-C. GENERATORS—WIDTH OF BELTS—DATA ON COPPER WIRE.

SAFETY RULES

FOR MEN HANDLING ELECTRICAL CIRCUITS OR APPARATUS

Rules.—These safety rules should be carefully read and studied.

Warnings.—Employees whose duties do not require them to approach or handle electrical equipment and lines should keep away from such equipment or lines.

They should cultivate the habit of being cautious, heed warning signs and signals, and always warn others when seen in danger near live equipment or lines.

Inexperienced Employees.—No employee should do work for which he is not properly qualified on or about live equipment or lines, except under the direct supervision of an experienced or properly qualified person.

If an employee is in doubt as to the proper performance of any work assigned, he should request instructions of foreman or other responsible person. DON'T TAKE CHANCES.

Workmen whose employment incidentally brings them in the neighborhood of electrical supply equipment or lines, with the dangers of which they are not familiar, should proceed with their work only when authorized. They should be accompanied by a properly qualified and authorized person, whose instructions must be strictly obeyed.

Personal Caution.—Employees about live equipment or lines should consider the effect of each act, and do nothing which may endanger themselves or others. Employees should be careful always to place themselves in a safe and secure position to avoid slipping, stumbling, or moving backward against live parts. The care exercised by others should not be relied on for protection.

REMEMBER, PERSONAL CAUTION IS THE GREATEST SAFEGUARD AFTER ALL

Clothing.—Employees should wear suitable clothing while working on or about live equipment and lines. In particular, they should keep sleeves down and should avoid wearing unnecessary metal articles, celluloid collars, celluloid or metal cap visors or similar articles. Near live or moving parts, loose clothing and shoes that slip easily on floors worked upon should not be worn.

Safety Devices.—Safety devices provided to make the work less hazardous, should always be used, but entire reliance should not be placed on them as any safety device may get out of order and become ineffective, therefore, such devices or tools should be first examined to make sure that they are suitable and in good condition.

Safety Belts.—Employees should not work in elevated positions unless secured from falling by approved safety belts or by other adequate means.

Safety belts, whether owned by the company or by the individual workmen, should be periodically inspected.

Eye Protectors.—Suitable eye protectors should be worn by men working where an electric arc may be drawn, with resultant flash to eyes.

Approved safety goggles should be worn to prevent injury by flying particles when chiseling concrete, stone or brick for the support of wiring devices or electrical apparatus.

Rubber Gloves.—Rubber gloves should be used only in special cases, and care must be taken to see that they are in good condition.

Danger Signs.—Approved danger signs should be placed at all points where men may accidentally come in contact with live wires, and should also be placed at suitable places when men are working overhead, to prevent passerby from injury from falling tools, etc. Danger signs should be removed when the danger is past.

Manholes.—When a cover is removed from a manhole, the hole must be properly guarded by railing, danger sign or red flag. An additional man stationed at the opening is often advisable.

Ladders.—No imperfect or defective ladders should be used. All ladders should be provided with approved non-slip shoes to prevent slipping. On cement, tile or iron floors, or other smooth surfaces, a board should be placed under the non-slip shoes.

Tools.—No imperfect or defective tool should be used. The handles of tools should be covered with rubber tape to prevent slipping and to reduce the possibility of short-circuits across them. Such taping, however, should not be relied upon for protection of workmen from shock. Heads of cold chisels, center punches, etc., should be occasionally dressed and not allowed to become mushroomed. Avoid the use of measuring tapes of metal or with metal woven into the fabric also brass bound rules and steel scales.

Rubber Shields.—When working on poles carrying lines of a potential higher than 600 volts, wiremen may use rubber shields across the wires to protect themselves while working on a selected wire.

Insulating Stands.—Employees should be properly insulated from the ground by a linoleum or rubber mat, insulated stool, wooden slat platform, or other suitable insulating material when working on circuits or operating high tension switches, especially the disconnecting lever type.

Circuits.—No repairs, alterations or examinations requiring handling of live circuits above 750 volts should be made, except in case of urgent need, and only when under the personal supervision of the foreman. All voltages must be considered dangerous by wiremen. Even though the voltage may not be great enough to produce a fatal shock, it may cause serious consequences by throwing workman from ladder or other overhead position. Except in emergencies, no employee should work alone on or near live circuits above 750 volts in wet weather or at night.

Circuits should be made dead whenever possible before work is begun. Dead circuits should be treated as if they were alive. This procedure develops a cautious nature and may sometimes prevent an accident caused by another person's error.

When working on series lamp circuits, employees should make sure that they are well insulated from the ground and that the current is off.

All circuits should be tagged or lettered so that they may be readily identified.

Whenever circuits are opened for repairs, alterations or examination, the control switch should be locked open and where switch construction permits, it should be padlocked. The disconnecting switches or cutouts should also be opened as an additional safeguard against accidental closing of circuit. The workman responsible for having the circuit opened should place on a controlling switch a tag bearing his name and a notice that the switch should not be closed until the tag is removed. No person other than the workman tagging the switch should be allowed to close such switch. Whenever it becomes necessary for the person tagging a switch to leave before the work is completed, as may be the case in a long job, he should go to the switch accompanied by the man who is to assume the responsibility, and remove his tag: his successor should then attach a similar tag to the switch.

Where it is not possible on account of conditions to tag open switches, the wires should be short-circuited and grounded between source of power and point where work is being done, and kept so until work is completed.

As an additional safeguard, circuits carrying 750 volts or or over, should be short-circuited and grounded even if the rules previously stated are observed.

Wiring.—All wiring must be done in accordance with Underwriter's Rules, National Bureau of Standards or local ordinances. Wires carelessly installed are dangerous and often are the cause of short-circuits and fires. Ends of wires should not be left exposed after cutting. If wires cannot be removed altogether, the ends should be well insulated.

The insulation on a wire should not be trusted for protection from shock. While the insulation may look perfect it may have deteriorated from age or exposure so it cannot be relied on.

When tapping live insulated wires, insulation should be removed from only one wire at a time. A second wire should not be exposed until the first tap is made and the joint insulated.

Connections between wires must be well made, the wires bound and soldered and the joint carefully insulated. When wires are held in contact by means of screws, care must be taken to see that the screws are set down tight. A slight movement of the wire while setting down screws will tend to make the joint tight.

Grounding.—Employees should assume that all circuits are grounded and insulate their bodies properly against all wires.

Frames of motors, switch boxes, transformers, etc., must be substantially grounded.

To avoid possible shock due to grounding when work is being done in damp places, extra precautions must be taken to insulate the body. This can generally be satisfactorily done by using a dry plank or board to stand on.

Operating Switches.—Switches should be left wide open when in open position, and fully closed when in the closed position.

Switches should not be closed in a hesitating manner or by tapping the blades against the contacts to ascertain if the circuit is on, but should be closed in a firm, positive manner, using sufficient force to make full contact of blades. A switch should not be closed without full knowledge of the condition of the circuit.

Fuses and Cutouts.—Fuses should be pulled or replaced, using insulated fuse pullers. The live end of the fuse should be pulled out first and when replacing fuses the live end should be put in last.

Power Plant and Motor Attendants.—Do not allow oil cans, tools, dusters or wiping cloths to catch in moving parts of machines. In passing any switchboard or machine in operation, do not touch it unnecessarily nor allow metal tools or other metal objects to touch the apparatus or its connections. Do not use iron or tin oil cans near field magnets. Use only oilers, dusters, or wipers with insulated handles in or about commutators, switches, switchboards or other electrical equipment.

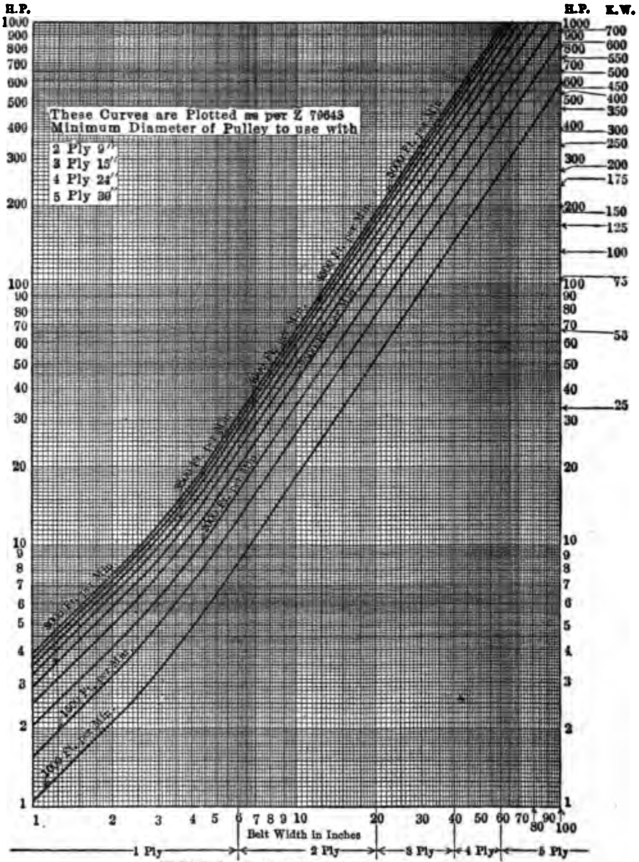
Resuscitation.—The prone pressure method of resuscitation should be used in all cases of electrical shock. This method should therefore be thoroughly understood by all men handling electrical circuits or apparatus.

Observance of Rules.—The above rules cover some of the duties and precautions for the protection of wiremen and electricians; they must be observed by all men handling electrical circuits or apparatus.

STANDARD SIZES OF CABLES TO BE USED IN CONNECTION WITH DIRECT-CURRENT GENERATORS

The following table gives the size of cable to be used for the equalizer after the size of the main cable is determined upon. It will be noted in general that up to and including 750,000 cm. main cable, the same size cable is used for the equalizer. Above this, the equalizer cable is not less than one-half the main cable in circular mils.

Ampere range	Size of main cable	Size of equalizer cable
37- 56	No. 4 B. & S.	No. 4 B. & S.
57- 84	No. 2 B. & S.	No. 2 B. & S.
85- 124	No. 0 B. & S.	No. 0 B. & S.
125- 169	No. 000 B. & S.	No. 000 B. & S.
170- 184	No. 0000 B. & S.	No. 0000 B. & S.
185- 224	250,000 cm.	250,000 cm.
225- 264	300,000 cm.	300,000 cm.
265- 324	400,000 cm.	400,000 cm.
325- 374	500,000 cm.	500,000 cm.
375- 499	750,000 cm.	750,000 cm.
500- 649	1,000,000 cm.	500,000 cm.
650- 749	1,250,000 cm.	750,000 cm.
750- 899	1,500,000 cm.	750,000 cm.
900-1,099	2,000,000 cm.	1,000,000 cm.
1,000-1,299	2-1,000,000 cm.	1,000,000 cm.
1,300-1,599	2-1,250,000 cm.	1,250,000 cm.
1,600-2,249	2-2,000,000 cm.	2,000,000 cm.
2,250-2,649	3-1,500,000 cm.	2-1,500,000 cm.
2,650-3,349	3-2,000,000 cm.	2-2,000,000 cm.
3,350-3,599	4-1,500,000 cm.	2-1,500,000 cm.
3,600-4,399	4-2,000,000 cm.	2-2,000,000 cm.
4,400-5,599	5-2,000,000 cm.	3-2,000,000 cm.
5,600-6,600	6-2,000,000 cm.	3-2,000,000 cm.



WIDTH OF BELTS (LEATHER)

Cast Iron, Paper & Wood Pulleys

Fig. 109.

DATA ON COPPER WIRE

Diam. mils bare	Area cross section		Diameter over insulation				Per 1000 feet				
	Circular mils	Square mils	Single-cotton	Double-cotton	*Triple-cotton	Enamel	Pounds bare	Ohms			
								20°	40°	75°	100°
460	212,000	166,000	.....	.....	.....	.....	640	0.0491	0.0529	0.0597	0.0645
410	168 000	132,000	.....	.....	.....	.....	509	0.0617	0.0665	0.0751	0.0811
365	133,000	105,000	.....	.....	.....	.....	405	0.0776	0.0837	0.0944	0.102
325	106,000	83,000	.....	339	343	.....	320	0.0981	0.106	0.119	0.129
289	83,500	65,600	.....	303	307	.....	253	0.124	0.134	0.151	0.163
258	66,600	52,300	.....	272	276	.....	202	0.156	0.168	0.189	0.205
229	52,400	41,200	.....	242	247	.....	159	0.198	0.213	0.240	0.260
220	48,400	38,000	.....	233	238	.....	146	0.214	0.231	0.261	0.282
204	41,600	32,700	211	216	220	.....	126	0.249	0.269	0.303	0.328
193	37,250	29,200	200	205	209	.....	113	0.279	0.301	0.339	0.367
182	33,100	26,000	189	194	198	.....	100	0.313	0.338	0.381	0.412
172	29,600	23,200	179	184	188	.....	89.4	0.351	0.379	0.427	0.462
162	26,200	20,600	169	174	178	.....	79.4	0.395	0.426	0.481	0.520
153	23,400	18,350	160	165	169	.....	70.7	0.444	0.479	0.540	0.584
144	20,700	16,300	151	156	160	.....	62.8	0.500	0.539	0.608	0.657
134	18,000	14,100	141	146	150	138	54.3	0.578	0.623	0.703	0.760
128	16,400	12,900	135	140	144	132	49.7	0.632	0.682	0.768	0.831
120	14,400	11,300	127	132	136	124	43.6	0.721	0.777	0.877	0.948
114	13,000	10,200	121	126	130	118	39.3	0.799	0.861	0.971	1.05
109	11,900	9,350	115	119	123	113	36	0.871	0.939	1.06	1.15
102	10,400	8,170	108	112	116	105	31.5	0.997	1.08	1.21	1.31
95	9,030	7,090	101	105	109	98	27.3	1.15	1.24	1.40	1.51
91	8,280	6,500	97	101	105	94	25.1	1.25	1.35	1.52	1.65
86	7,400	5,810	92	96	100	89	22.4	1.40	1.51	1.71	1.85
81	6,560	5,150	87	91	95	84	19.9	1.58	1.71	1.92	2.08
76	5,780	4,540	82	86	90	79	17.5	1.80	1.94	2.18	2.36
72	5,180	4,070	78	82	86	75	15.7	2.00	2.16	2.43	2.63
68	4,620	3,630	74	78	82	71	14.0	2.24	2.42	2.73	2.95
64	4,100	3,220	70	74	78	67	12.4	2.53	2.73	3.08	3.33
61	3,720	2,920	67	71	75	64	11.3	2.79	3.01	3.39	3.67
57	3,250	2,550	63	67	71	60	9.83	3.19	3.44	3.89	4.20
54	2,920	2,290	60	64	68	57	8.83	3.56	3.84	4.33	4.68
51	2,600	2,040	56	59	63	53.5	7.86	3.99	4.31	4.86	5.25
49	2,400	1,890	54	57	61	51.5	7.28	4.31	4.65	5.24	5.67
45	2,030	1,590	50	53	57	47.5	6.13	5.12	5.52	6.23	6.74

42	1,760	1,390	47	50	54	44.5	5.36	5.86	6.32	7.13	7.71
40	1,600	1,260	45	48	52	42	4.86	6.46	6.97	7.86	8.50
38.5	1,482	1,164	43.5	46.5	50.5	40.5	4.48	7.02	7.57	8.54	9.24
36	1,296	1,018	40	44	48	38	3.93	8.01	8.63	9.74	10.5
32	1,020	804	36	40	44	34	3.10	10.1	10.9	12.3	13.3
30.5	930	731	34.5	38.5	42.5	32.5	2.81	11.1	12.0	13.5	14.7
28.5	812	638	32.5	36.5	40.5	30.5	2.46	12.8	13.8	15.5	16.8
25.5	650	511	29.5	33.5	37.5	27.5	1.97	15.9	17.2	19.4	21.0
23	529	415	27	31	35	25	1.60	19.6	21.2	23.9	25.8
20	400	314	24	28	32	22	1.21	25.9	28.0	31.6	34.1
18	324	254	22	26	.....	20	0.979	32.1	34.6	39.0	42.2
16	256	201	20	24	.....	17.5	0.775	40.5	43.7	49.3	53.3
14	196	154	18	22	.....	15.5	0.594	52.9	57.0	64.3	69.5
12.6	159	125	16.6	20.6	.....	14	0.482	65.2	70.3	79.3	85.7
11	121	95	15	19	.....	12	0.366	85.7	92.4	104	113
10	100	78.5	14	18	.....	11	0.303	104	112	126	136
9	81	63.6	13	17	.....	10	0.245	128	138	156	168
8	64	50.3	12	16	.....	8.9	0.194	162	175	197	213
7	49	38.5	11	15	.....	7.9	0.148	212	228	257	278
6.3	39.7	31.2	10.3	14.3	.....	7.1	0.120	261	282	318	343
5.6	31.4	24.6	9.6	13.6	.....	6.4	0.095	331	357	403	435
5	25	19.6	8.5	12	.....	5.7	0.076	416	448	506	546

NOTES

Table applies to standard annealed copper of circular section as described in I. E. C. Rules (Standardisation Rules of A. I. E. E. of 1914). Calculations are correct within ½ of 1 per cent.

Permissible Variations:

Bare diameter, 1 per cent. high or low, down to 10 mils inclusive, and 0.1 mil high or low, below 10 mils.

Cross section, 2 per cent. high or low, down to and including 10 mils diameter.

Weight, 2 per cent. high or low, down to and including 10 mils diameter.

Diameter cotton-covered and enamelled is maximum permissible.

Resistance. Specific resistance may be 1.83 per cent. high, hence with diameter variations, resistance may vary up to 3.83 per cent. high.

When enamel wire is cotton covered there should be added to the diameter of the enamel wire the same increase in diameter that is due to the cotton covering of bare wire.

* Double cotton covering to any specified thickness greater than standard can be supplied as a substitute for T. C. C. at a lower cost.

FUNDAMENTAL DATA

Weight.—1 cubic inch of copper weighs 0.3212 lb. at 20 deg. C.

Resistance at 20 Deg. C.—The resistance of a wire 1 meter long and 1 sq. mm. cross section is $\frac{1}{58}$ ohm or 0.017241 ohm.

Resistance of 1,000 ft. wire of 1 cir. mil is 10,370 ohm at 20 deg. C.
11,185 ohm at 40 deg. C.
12,614 ohm at 75 deg. C.
13,633 ohm at 100 deg. C.

Resistance of 1,000 ft. wire of 1 sq. mil is 8,145 ohm at 20 deg. C.
8,784 ohm at 40 deg. C.
9,907 ohm at 75 deg. C.
10,710 ohm at 100 deg. C.

Temperature Coefficient is 0.00393 or $\frac{1}{254.5}$ per degree C., from 20 deg. C.

Resistance at $T° = R$ (at 20 degrees) $(1 + 0.00393\,[T - 20])$

INDEX

OCT 27 1920

UNIVERSITY OF MICHIGAN
3 9015 00295 5907

[redacted]